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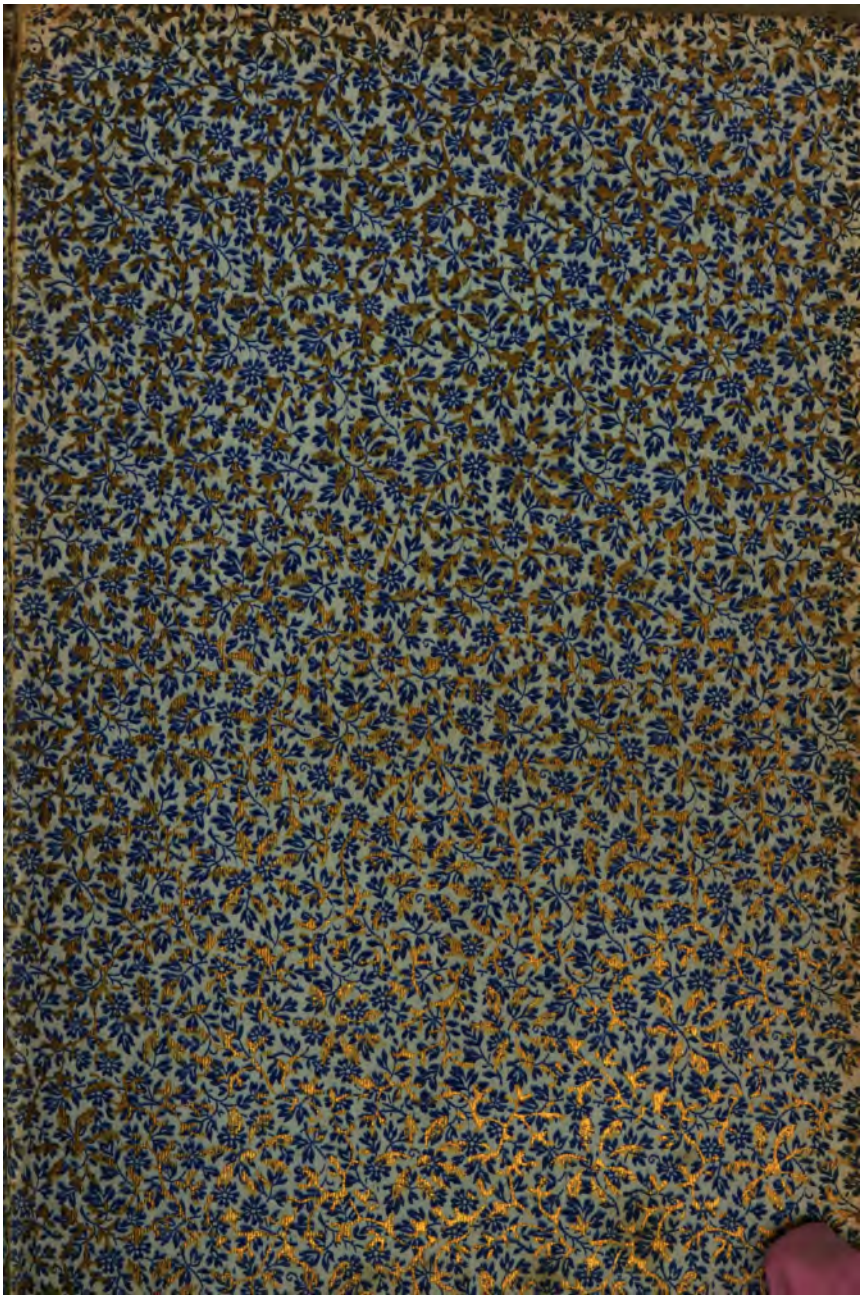

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Modern Illumination Theory and Practice

A handbook of practical information for the users of electric light, architects, contractors and electricians

By
HENRY C. HORSTMANN
and
VICTOR H. TOUSLEY

Authors of
Modern Wiring Diagrams and Descriptions, Modern Electrical Construction, Electrical Wiring and Construction Tables, Practical Armature and Magnet Winding, Electricians Operating and Testing Manual, Etc.

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By

Horstmann and Tousley

PREFACE

This work, similar to all others of the authors, is intended for the practical workman rather than the student of mere theoretical considerations. The aim has been to give as much of the theory as is needed to a thorough comprehension of the underlying principles, but to dwell with particular emphasis upon the practical points which must be considered in the laying out of illumination.

The matter has been treated in such a manner that it may be serviceable not only to electricians, but to architects, superintendents or managers of commercial or industrial establishments as well.

The systematic manner in which the various sources of illumination have been arranged and treated will appeal especially to the users of electric light who are not trained electricians.

In view of the present very much jumbled state of the art with regard to the preparing of plans and specifications, the chapter dealing with this phase cannot fail to interest all parties to contracts for wiring or illumination.

The chapter entitled "PRACTICAL CONSIDERATIONS" is intended to suggest all the peculiar and general requirements that obtain in the many different locations mentioned and it is suggested that this chapter

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be freely consulted in the planning of illumination.

The aim throughout has been to provide a thorough practical guide containing all the information needed to the successful installation of good illumination in such a manner as to be readily intelligible to all concerned in such work.

The thanks of the authors are due to Mr. James J. Dolan for assistance and helpful suggestions.

THE AUTHORS.

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CHAPTER I

LIGHT

The term, light, may be used either to denote the sensations peculiar to the retina of the eye which produce vision or the cause of these sensations. Light is sometimes considered as the cause and illumination as the effect but this distinction is not material and not much observed.

Light is a form of energy and can be converted into other forms and vice versa can be produced from other forms of energy. Electric lamps of various kinds are used to transform one kind of energy into light.

A heated body radiates energy in the form of waves into the surrounding space. The lower the temperature the longer will be these waves, but at the lower temperatures heat only is given off. As the temperature increases the waves become shorter and the red rays begin to appear. With continued increase in temperature shorter and shorter waves are produced giving rays of light of different colors until at certain temperature white light which is a mixture of all colors is emitted.

The shortest rays that are visible to the eye are the violet. Waves shorter than these are known as

the ultra violet. Waves that are longer than the red are known as the infra red rays.

The longest light waves, the red, are 0.0008 millimeters (0.8 micron, usually written 0.8 μ) and the shortest, the violet are 0.0004 millimeters or 0.4 μ in length.

The velocity of light is 188,000 miles per second and rays of light travel in straight lines unless interfered with by some intercepting medium. This interference may take the form of reflection, refraction or absorption.

The frequency of waves of light is different for the various colors, being highest for the shortest waves.

The length of light waves are in the order shown: RED, YELLOW, GREEN, BLUE, VIOLET.

When the rays from a source of light are spread out by the spectroscope according to their wave lengths that part which affects the eye is known as the visible spectrum. This is a band of light red at one end and violet at the other. Between these are various colors each merging imperceptibly into another.

The colors of the spectrum vary widely with the material, from the incandescence of which the rays of light forming it are produced.

The primary colors, speaking of the visible spectrum, from which all others can be produced are red, green and violet.

For pigments these colors are red, yellow and blue.

Light may be absorbed or reflected. Such bodies as appear perfectly black to us absorb nearly all of the light rays, while those that appear perfectly

white reflect nearly all of the rays. Between these black and white bodies there are others of all possible colors. These colors are produced by partial absorption of light. A red body for instance absorbs all but the red rays, a blue one all but the blue, etc.

The absorbing powers of certain bodies may be often employed to advantage to correct unpleasant or unsuitable colors of certain sources of illumination.

CHAPTER II

PRINCIPLES OF VISION

The manner in which we see can be made clear by reference to Figure 1 which is a diagram of the eye. The rays of light coming from the object at the left pass through the watery substance W; the pupil P, lens L and strike the retina R upon which the image is formed and communicated to the brain. I is the iris or colored part of the eye which has the power of expanding or contracting and thus adjusting the quantity of light which is to reach the retina. The lens L is also capable of adjustment but its action is only to focus the rays of light upon the retina.

The eye is in all respects similar in construction to any photographic camera, even in the formation of the image which is actually always upside down. No matter how we may turn a camera the image upon the ground glass will always be upside down but with a little experience we soon become used to it and never notice this condition any more. So also in vision, knowing from infancy how to correct the impressions of vision by the sense of touch we later automatically and unconsciously do so.

With young people the action of the pupil and lens are rapid and there is comparatively little

trouble in adjusting the eye to different distances and conditions of light. With advancing age both of these actions become more difficult, it requires a much longer time before the pupil of the eye can dilate sufficiently so that one coming from a well lighted room into a dark one can begin to see. Also, after looking for a while at a distance, an appreciable length of time is required before the lens can adjust itself so as to make reading possible.

The pupil always tends to adjust itself to such a size of opening as will admit a comfortable quantity of light to reach the retina. In this, however, it is to some extent affected by the desire of the person

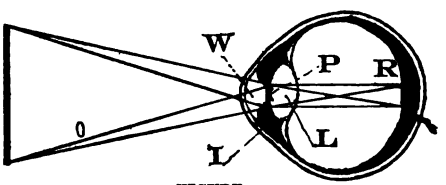


FIGURE 1

to see. If there is not sufficient light there will be considerable straining to enlarge the opening beyond its normal limits. If there is too much light the strain will be the opposite. If there are two conflicting conditions such as a bright light in the line of vision, or in contrast with deep shadows, or insufficient illumination, the adjustment will be such as to limit the light to what the eye can comfortably endure. This is the reason, for instance, that it is impossible to see past a bright light. This fact also points a moral in regard to average illumination. An

average illumination of a certain number of foot candles if made up of some very high and low intensities has really a meaning altogether different from that usually given to it. The high lights in spots do not add to the value of the light at the points of low intensity but rather detract from it. This is very often exemplified in stores, corridors, etc., subject to partial illumination by daylight. There are many such places where with the same lights burning by day and at night one can see better at night than by the dim daylight assisting. This is due to the fact that the bright lights from windows cause the pupil of the eye to close partially. It is also proven in many living rooms where at dusk one can improve the vision by drawing down the curtains.

Very injurious effects are also traceable to flickering lights. When the illumination is unsteady the pupil is constantly in motion with the result that it soon begins to pain and grow weary.

From the above we can deduce the following rules for illumination:

The quantity of light should be suited to the needs of the person using it. This not only must vary with the nature of the work done but also with the conditions of the eyes of the user.

The source of light should never be visible to the user. If it is impossible to place lights out of the ordinary range of vision they should be enclosed in diffusing globes. The more the intrinsic brilliancy is reduced the better will be the illumination.

Where work requiring bright light is done the

lighting should be so arranged that the light falling upon the work is the brightest in the room. When looking up the eye should obtain some relief from the high intensity and not be called upon to face a still greater intensity.

The illumination should be steady (not flicker), and there should be no streaks such as are often obtained from smooth reflectors.

The light source should preferably be over the right or left shoulder depending upon whether the user is right or left handed. If the source of light is in front of the user the glare coming from bright objects may be very uncomfortable.

We distinguish objects either through their outline, relief, color or perspective.

Outline and relief require some shadows to be easily noticeable. Colors require attention in so far that many of the artificial illuminants produce great distortion in color values.

The use of lamps having a high intrinsic brilliancy in the ordinary line of vision produces the effect commonly known as glare. The intrinsic brilliancy of a source of light that can be placed in the ordinary line of vision without causing eye strain varies with different conditions and is less for a lamp having a large luminous surface than for a smaller one. Even a secondary source of light of comparatively low intensity, such as a wall or ceiling, if continually in the line of vision may become disagreeable, especially if there is much contrast in the intensity of illumination. As a general rule the intrinsic brilliancy of a lamp placed in the line of vision should not be

more than 4 or 5 candle power per square inch and preferably less.

In the following table are given the approximate intrinsic brilliancy of various sources of light.

	Candle power per sq. inch
Moore tube	0.3 to 1.75
Opal shaded incandescent lamp	0.5 to 3.0
Frosted incandescent lamp	2 to 8
Candle	3 to 4
Open gas flame	4 to 8
Kerosene lamp	3 to 8
Mercury vapor lamp	10 to 20
Welsbach gas mantle	20 to 40
Acetylene gas flame	40 to 60
Enclosed arc, alternating (opal inner globe),	100 to 200
Enclosed arc lamp (direct current)	100 to 500
Carbon filament lamp	300 to 500
Graphitized filament lamp	600 to 650
Tantalum filament lamp	700 to 800
Tungsten filament lamp	850 to 1,050
Nernst glower (clear globe)	2,000 to 3,000
Luminous arc lamp (clear globe)	4,000
Flaming arc lamp (clear globe)	5,000
Calcium light	5,000
Open arc lamp (clear globe)	10,000 to 100,000
Sun on horizon	2,000
Sun 30° above horizon	500,000
Sun at zenith	600,000

CHAPTER III

REFLECTION, REFRACTION AND DIFFUSION

Light rays move along straight lines unless deflected by some intercepting medium. This interception may result in either refraction or reflection and both may occur at the same time.

A part of the light is absorbed and is generally converted into heat and is wasted as far as illumination is concerned. If the reflecting surface is smooth the light is reflected at an angle equal to that at which it is impinged and the reflection is said to be regular or specular. The intensity of the light will be reduced by absorption and this varies with the degree of polish and the nature of the reflecting medium. A table of percentage of reflection by different colors and substances is given in Chapter VI. The color of the light will also be changed if the reflecting medium is colored.

The principle of regular reflection is shown in Figure 2, the impinging and reflected rays making always the same angle but on opposite sides of the perpendicular.

Regular reflection may in some cases be very trying to the eyes. This is well illustrated in books printed on highly polished paper. If such a book is

held at an angle permitting of direct reflection to the eye it will be very difficult and annoying to read.

If the reflecting surface is rough or irregular every little section of it presents a different angle to

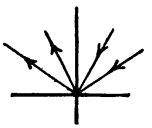


FIGURE 2

FIGURE 3

the rays of light and the reflection is in all possible directions. Such surfaces may be of such a character that some of the rays are reflected several times on the surface. This is known as irregular or diffuse reflection.

The principle of irregular reflection is shown in Figure 3.

When rays of light pass from one medium to another of different density, such for instance as from air into water or glass they are refracted or bent out of their course. If both surfaces of a transparent material are perfectly smooth and parallel the two refractions are equal and opposite and the direction

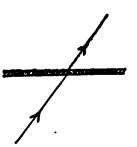


FIGURE 4

of the rays is not materially changed. This is the case with good window glass and is illustrated in Figure 4.

The degree of refraction varies with different materials and for each there is a definite ratio between the sine of the angle of incidence (measured from the perpendicular) and the sine of the angle at which the ray continues in the denser medium. This is known as the index of refraction and for certain kinds of glass is about 1.5, for water it is 1.3 and for the diamond about 2.4. In passing from a denser medium into air the index of refraction is the recip-

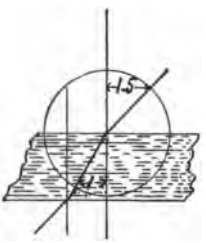


FIGURE 5

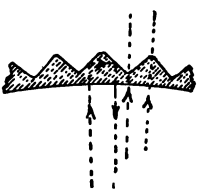


FIGURE 6

rocal of the above. This is illustrated in Figure 5 where the angles and the refraction for glass are shown.

A part of the rays of light are always reflected and a part are absorbed. It will also be seen from the above that rays of light which strike the glass at right angles or perpendicularly are not refracted at all but pass straight through the glass.

Total reflection can also be obtained by the use of prisms as shown in Figure 6 and this is the principle upon which prismatic glass reflectors are based. It must, however, be understood that the filament of an incandescent lamp being of quite appreciable size

and much larger than any of the prisms used, the course of the rays of light emanating from it is not as simple as indicated but each prism receives rays of light at many different angles and the result is not only reflection but diffusion due to refraction as well. Furthermore the crests and the valleys of the prisms are always slightly rounding and some of the light is transmitted direct.

Diffusion is due to rays of light crossing each other or being scattered by irregular reflecting surfaces. This may be brought about either by irregular reflection or by transmission through prismatic, ground or opal glass or by rough surfaces of transparent or translucent media of any kind.

The greater the diffusion the less shadows will be noticed. Because diffused light is also more even the eye can stand a much higher intensity than with direct light and strong shadows. This is why daylight while of high intensity is still easier on the eyes than any artificial illuminant.

CHAPTER IV

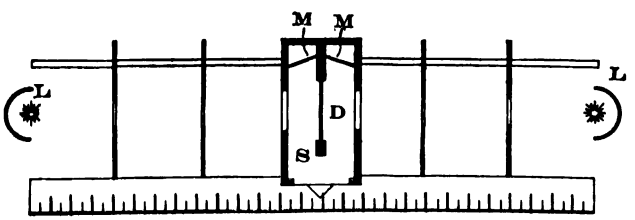
PHOTOMETRY

Photometry is the art of measurement of light and the comparison of different sources of light.

Light is a physiological rather than a physical quantity and cannot be measured in terms of any absolute system of measurement. The measurement of illumination or light is therefore based upon arbitrary standards. Formerly the standard of light measurement was a candle made according to certain specifications and used in a certain way. The manipulation of these standards required much care in order to assure that results would be at all correct. Flame standards of this kind are still used to a certain extent, but for all practical purposes carefully seasoned carbon filament lamps are usually preferred. These secondary standards are rated in international candles which is the recognized unit in most countries.

There are many types of photometers but most of them employ one of the three principles herein described. In all of them it is necessary to compare illumination by means of the eye and this introduces a certain error since it is seldom that two observers will see things exactly alike.

The most common and the most practical kind of photometer is that known as Bunsen's. The measurement of light in this photometer is made by means of a paper disk in the center of which a small spot, often in the form of a star, is impregnated with grease of some sort. This treatment makes that part of the disk translucent and if it be now placed between two sources of light of unequal intensity the spot will appear darker than the paper on one side and lighter on the other. If the disk is shifted to such a position that the light striking it from both sides is equal the spot will disappear.



A diagrammatic view of a Bunsen photometer is given in Figure 7 in which D represents the paper disk; S the movable sight box enclosing it; M and M a pair of mirrors and L L the standard light and the light to be measured. The standard lamp of known candle power is set up at one end and the lamp to be measured at the other. The sight box is now shifted until a position is found at which the grease spot is no longer visible. The candle powers of the two lamps are now in the same proportion to each other as the square of their distance from the disk. As an

example, if balance is obtained with the disk 9 divisions from the standard lamp and 18 from the lamp under test the candle power of the test lamp is four times that of the standard lamp.

In order that these tests may be accurate it is necessary to arrange that only direct rays and no reflected light from either of the lamps may reach the disk. To this end each lamp is generally enclosed in a hood of black velvet or some other dull black material as indicated and between each lamp and the sight box there are interposed a number of black screens with openings in the center so as to admit sufficient light to reach the disk, while at the same time preventing any reflected light from walls, etc., from reaching it. This photometer as here outlined is quite a large affair and placed inside of a room which forms its only enclosure and which must therefore also be painted black throughout.

The object of the two mirrors M M is to enable the operator to view both sides of the disk at the same time and thus judge more accurately when the illumination on the two sides is equal. As there is often a considerable difference in the two sides of the disk and also in the powers of observation of the operator, it is advisable to turn the disk in the box after making the first setting and check up with a second setting. If there is any difference between the two the average of the settings should be taken.

The candle power of an incandescent lamp varies considerably, not only in the upper and lower hemispheres, but also in different directions horizontally. In a certain direction there will be practically only

the illumination of one-half of the filament, while in other directions there will be the illumination of both. In order to get the mean illumination in all directions the lamp must be turned and measurements made in a large number of different directions. This is a very tedious affair and in order to avoid it the lamp under test is placed in a socket arranged so that it can be rapidly rotated

The speed of rotation varies with different lamps and should never be greater than is necessary to make the light appear steady. If it is too slow the light

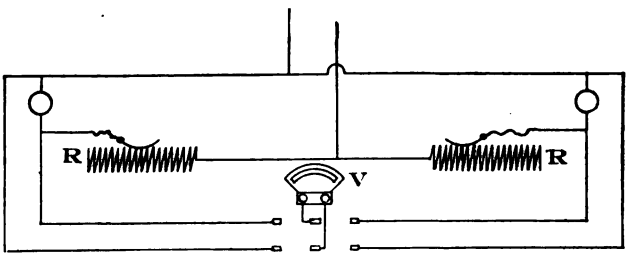


FIGURE 8

will flicker, if too fast there will be distortion of the filament by centrifugal force. The greater the number of turns of filament in a lamp the slower may be the speed of rotation.

In order that the candle power of lamps at all angles vertically may be tested universal rotaters have been devised. With one of these the lamp may be tilted at any angle and rotated.

A diagram of a good method of wiring to lamps for testing purposes is given in Figure 8. R and R are two small rheostats by means of which the current

passing through, or the voltage to be maintained at the corresponding lamp may be regulated. V is a voltmeter provided with a double throw switch by which the operator can measure the voltage at either lamp. To make the test, the voltage of the standard lamp is first brought to its proper value. Next the lamp to be tested is inserted and the voltage adjusted to the proper value when the test may be made as above described. If instead of measuring the candle power of the lamp it is intended to determine what the voltage must be in order to attain a certain candle power, the sight box of the photometer may be set at the point on the scale corresponding to the ratio of the candle powers desired and the voltage of the lamp under test raised until the candle power is equal to this.

In order to determine the exact point at which the sight box must be set, extract the square root of the ratio of the candle power desired to the candle power of the standard lamp and add 1 and by this sum divide the distance between lamps. Next multiply the dividend thus obtained by the aforementioned square root. The result will be the point at which the sight box must be set in order that the illumination may balance.

Example: Suppose the standard lamp to be of 8 candlepower and we desire to find the point at which the illumination on the two sides of the disk must balance for a 32-candlepower lamp. The ratio of the candlepowers is 4 to 1; the square root of 4 is 2; adding 2 and 1 we have 3 by which to divide the distance between lamps. Suppose this distance to be

100 inches we obtain as a dividend 33 1/3; multiplying this by 2 we have a setting of 66 2/3 inches from the lamp to be tested and 33 1/3 inches from the standard lamp. The squares of the distances are now as 4 is to 1, and when the voltage of the lamp to be tested has been raised sufficiently to produce balance on the screen the candlepower of the lamp under test is 4 times that of the standard lamp.

It has been mentioned above that errors are very likely to be made either from inaccuracy of observation or unevenness of the greased portion of the disk. In order to reduce the chances of error to a minimum and avoid the necessity of reversing the disk at every setting what is known as "The substitution method" is often employed. This method is as follows: At one side of the sight box some well seasoned lamp is set up and fastened by a bar to the sight box so that no matter how the latter may be moved the lamp will move with it and remain at a constant distance. This lamp thus arranged furnishes a permanent illumination for one side of the screen. On the other side, at its regular place, the standard lamp is set up and the sight box may now be shifted until balance is obtained. A memorandum of the distance at which the standard lamp is from the screen when balance is obtained must be made.

The standard may now be removed and one of the lamps to be tested put in its place and the photometer again shifted until balance is obtained. The candlepower of the lamp to be tested is now to the candlepower of the standard lamp directly as the

squares of their distances from the screen when balance is obtained.

Example: Suppose balance to be obtained with the standard lamp 32 inches from the screen and again with the test lamp at 40 inches. The square of 32 is 1024 and that of 40 is 1600 so that the candlepower of the lamp under test is equal to $\frac{1600}{1024} \times I$; I being the candlepower of the standard lamp which must of course be known. It will be noticed from

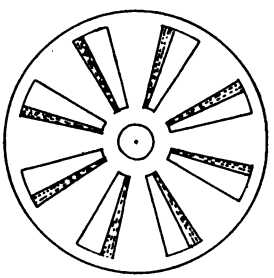


FIGURE 9

the above that the candlepower of the first lamp need not be known. It must, however, be such and fastened at such a distance from the screen that the measurement of the other lamps will fall within the range of the photometer. The lamp used here as a secondary standard should be well seasoned so that its candlepower may be as steady as possible.

With many forms of lamps the intensity is so great that they cannot readily be compared directly with standard lamps upon the ordinary photometer. Va-

rious means are sometimes employed in such cases to reduce the illumination. Among these the sectored disk is perhaps the most important and the easiest applied. It is illustrated in Figure 9 and as here shown consists of two circular disks out of which a certain proportion of material has been cut. By sliding one over the other the openings can be regulated to any desired size. The light to be measured is set up so that it can reach the photometer screen

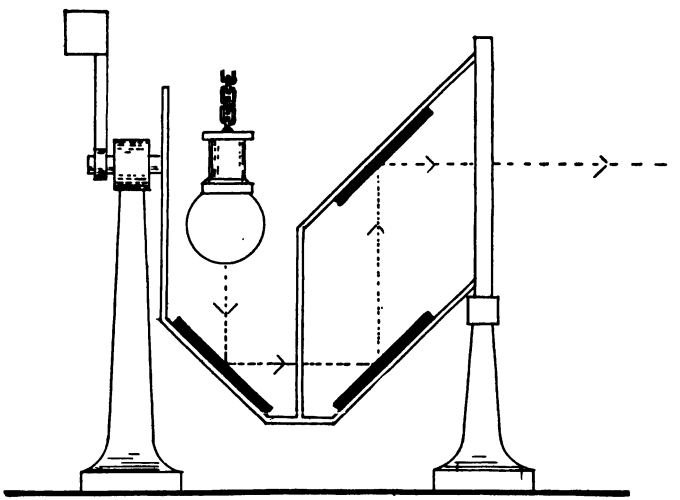


FIGURE 10

only through the openings in the disk while the disk is being rapidly revolved. Under these circumstances it can readily be seen that only a portion of the total light falling upon the disk will be allowed to pass through and this amount is proportional to the size of the openings.

Other means of reducing intensity are; glass arranged to absorb a known percentage of the illumination or adjustable diaphragms. The latter are used only with diffusing media of some kind or with lenses.

Figure 10 shows an arrangement of three mirrors which is sometimes used for the measurement of the candlepower of arc or Nernst lamps. Such lamps

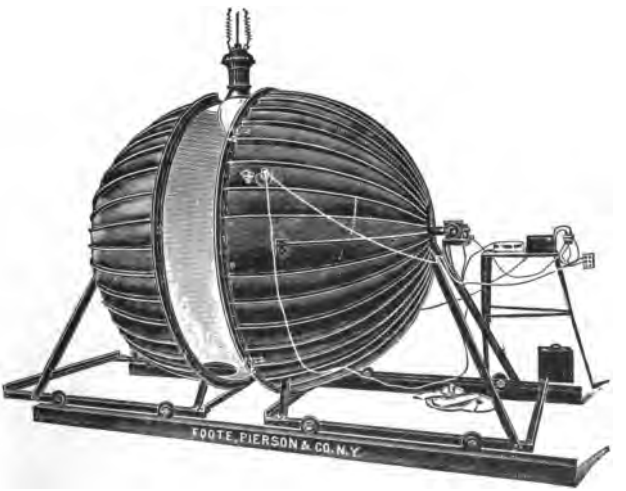


FIGURE 11

cannot be tilted like incandescent lamps and therefore to obtain the intensity at different angles the mirrors are arranged so they can be revolved around the lamp. As shown in the sketch they are at the bottom of lamp and rays of light emanating from the lowest part of the globe are being transmitted to

the photometer screen as indicated by dotted lines. The measurement of arc lamps required great patience owing to the fact that the arc is nearly always unsteady and traveling around the carbons.

The candlepower of arc lamps is also often measured by placing them on the inside of suitable spheres. See Figure 11. These spheres are coated on the inside with certain reflecting media and under such circumstances it can be shown that the illumination

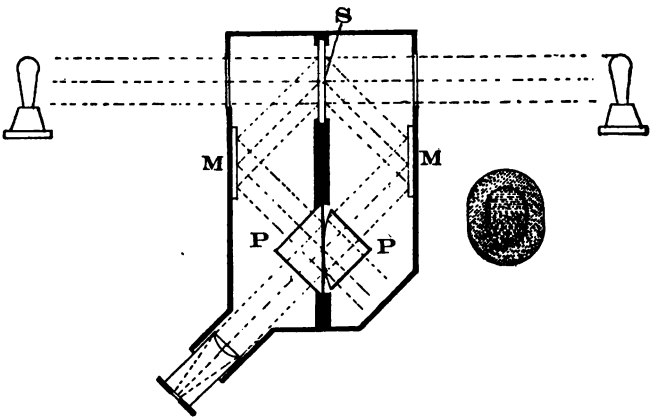


FIGURE 12

on all parts inside the sphere is practically uniform. If there is a suitable window placed in the side of such a sphere the brightness of this window will indicate the candlepower of the lamp within the sphere.

The form of photometer we have discussed so far is suitable only for use as a stationary instrument, it being too large and cumbersome to move about.

The principle upon which a large number of the portable photometers are constructed is shown in Figure 12. This is known as the Lummer-Brodhun photometer. In the Figure S is an opaque reflecting and diffusing screen by means of which the rays of light from the two lamps shown at right and left are reflected to the mirrors M and M respectively. From these mirrors they are again reflected to two prisms P and P. These prisms are cut to the shapes shown, their centers being in perfect contact while the edges of the one are ground away so that they do not touch the other.

In the center where the two surfaces touch the rays of light pass through in straight lines, while those striking along the outer edges are totally reflected, as indicated by dotted lines. Thus the center ray coming from the lamp at the right strikes S, mirror M and passes straight through the two prisms, furnishing an illumination to the central part of prism P proportional to the intensity of the lamp at the right. The outer rays of light from the same lamp are reflected by the curved surface of the prism P and do not appear at all.

From the lamp at the left the center rays are reflected in the same manner and pass through the two prisms, crossing the part illuminated by the lamp at the right but do not add to the illumination. The outer rays from the lamp at the left, however, are totally reflected by the prism P and thus appear to be illuminating the outer edges of the prism.

Looking through the eye piece we can now see two fields of light. The central field is due to the lamp

at the right and the outer field to the lamp at the left. The photometer may now be shifted or the lamps adjusted until the two fields are of the same intensity, when the candle powers of the lamps will be in the same ration to each other as with the Bunsen photometer.

Figure 13 shows a commercial form of instrument embodying the foregoing principles. The Sharp-Millar photometer consists of a long box which may

FIGURE 13

be mounted for convenience on a tripod. The box is light tight, the inside of it being painted a dead black. A working standard electric lamp is mounted in the box on a moving slide. The light from the lamp falls on a ground glass window inside the box and near one end. At one end of the box a round aperture is placed, fitted with an elbow tube which has a diffusing glass illumination test plate at its outer end and a mirror at the elbow for reflecting the light axially into the box. Just within is a sensitive photometric prism of the Lummer-Brodhun type,

whereby the brightness of the ground glass illuminated by the working standard lamp and that of the illumination test plate can be matched very exactly. It is then simply necessary to move the lamp back and forth until there is an even illumination all over the screen. The lamp is moved along the box by means of a knob on the side. A pointer on a scale at the sides shows its positon. This scale is calibrated to read directly either in foot candles or in candle power. The necessity for any calculation is thus done away with.

For measuring light of high intensities, a set of absorbing screens is provided. By inserting these screens the light admitted may be limited to any desired amount. For instance a screen may be put in which will let only a tenth of the light through. The correct reading of the outside illumination will then be ten times that shown on the scale.

In determining the apparent candle power of headlights, the instrument may be set up at any known distance from the headlight and the illumination shown multiplied by the square of the distance. By taking readings at various points around the headlight and multiplying each by the square of the distance the distribution curve of the headlight can be found.

To get the candle power of any light source it is simply necessary to multiply the foot candle readings by the square of the distance from the lamp. That is, an illumination of one candle foot at a distance of 4 feet from the lamp shows the lamp to be of 16 candle power.

The principal precaution to be observed in the use of the instrument is to have the standard lamp burning at the proper voltage. This may be checked up by placing a lamp of known candle power at a known distance and figuring what the illumination ought to be. Then set the instrument at this reading

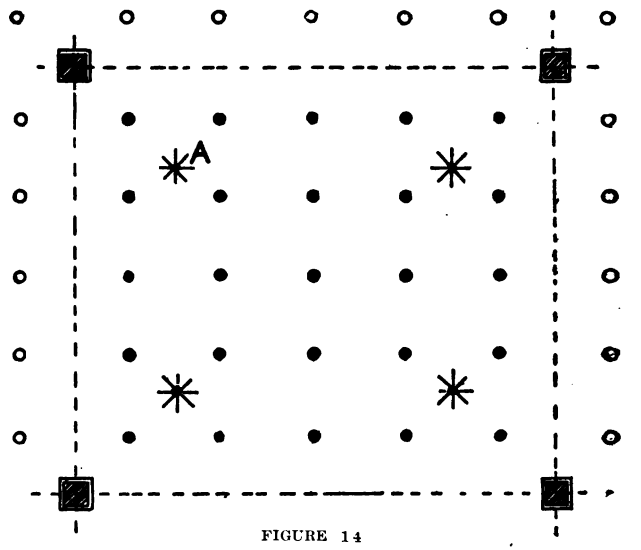


FIGURE 14

and adjust the rheostat until this reading is actually obtained. It must be noted that as the rheostat heats up the resistance changes and adjustment during the test may become necessary. In fact, it is advisable to have a voltmeter on the circuit and read it simultaneously with the illumination, then if there happens to be a drop in voltage, allowance for this can be made in the computations.

It is always advisable to check up the instrument before and after each test, as something may have happened to the lamp in the instrument. It is always well to have this lamp aged sufficiently to give a steady candle power.

In checking up the instrument for any given test it is best to use a standard lamp of the same type as the one to be tested. For a carbon or Gem test, use a carbon lamp. For a Mazda or tantalum test, use a Mazda. For an arc lamp test, a carbon standard has proven very satisfactory.

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9	3.7	3.78	3.8	114
10	3.62	3.6	3.6	115
11	3.7	3.71	3.72	115
12	3.9	3.8	3.89	115
13	3.94	3.78	3.8	115
14	3.5	3.62	3.42	115
15	3.96	3.94	3.9	115
16	3.68	3.56	3.53	114
17	3.54	3.6	3.76	114
18	3.81	3.72	3.7	114
19	3.65	3.72	3.8	114
20	3.71	3.68	3.65	114
21	3.57	3.7	3.59	114
22	3.72	3.68	3.58	115
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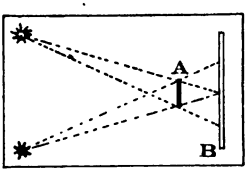

FIGURE 15.

two shadows adjacent to each other which can easily be compared. When the lamps are adjusted at such distances that the two shadows are equal, the candle-powers of the lamps are in proportion to the squares of their distance from the light screen. The angles at which the lamps are set should be the same.

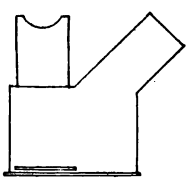

FIGURE 16

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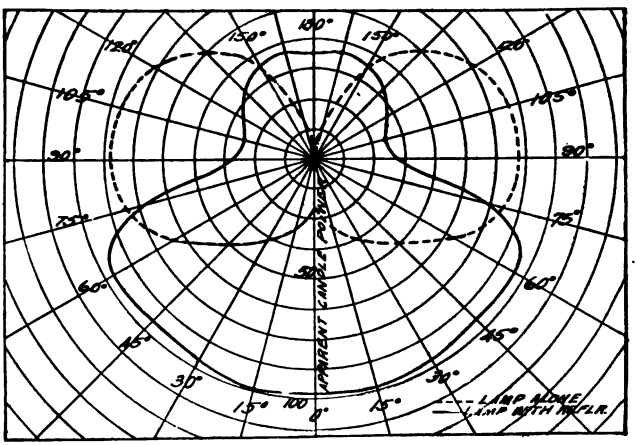

FIGURE 17

The measurements of candle power obtained by the use of any photometer are plotted upon sheets of paper ruled as shown in Figure 17. The angle at which the lamp is tilted or at which it is suspended above the photometer must be noted and the candle-power observed at those angles marked off at the corresponding angles on the paper. The greater the number of observations made, the more accurate

will be the curve which is drawn by combining all of the points marked off at the various angles.

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is greater or less it follows that we need but multiply it by 12.56 in order to obtain the total lumens emitted.

The above is simple enough so long as the source of light is equal in all directions; if it is not we must find the mean illumination and multiply this as above. The number of lumens emitted in any direction will always be equal to the product of the candle power and the surface over which this intensity is main-

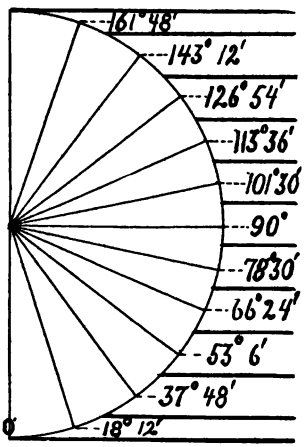

FIGURE 18

tained. For varying intensities we must, therefore, divide the surface of the sphere into a number of sections. Fortunately this is very easily accomplished.

Referring to Figure 18, we have at the left a drawing representing one-half of a sphere such as is generally used for laying out polar diagrams of intensity of illumination. By means of the heavy lines the outline of this hemisphere is divided into ten parts

of equal height or altitude. It is shown in treatises on mathematics that the surface of a section or zone of such a sphere is exactly proportional to its altitude and if we divide it into 10 parts of equal altitude each such zone will contain the same area. If we now find the mean intensity or candle power effective in any of these zones and multiply it by the surface of the zone we shall obtain the number of lumens given off in that zone.

In the figure there are 11 radial lines and each of these lines is laid out in the center of one of the ten zones. If we assume that the candle power as indicated in the photometric curve is fairly uniform, or that it has about its average value where the radial line crosses the curve, we need but take the candle-power readings at each of the 11 intersections, add them together and divide by 11 in order to find the mean candle power. To find the total number of lumens we must multiply the mean candle power by 12.56.

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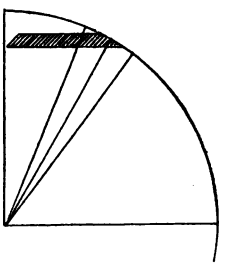

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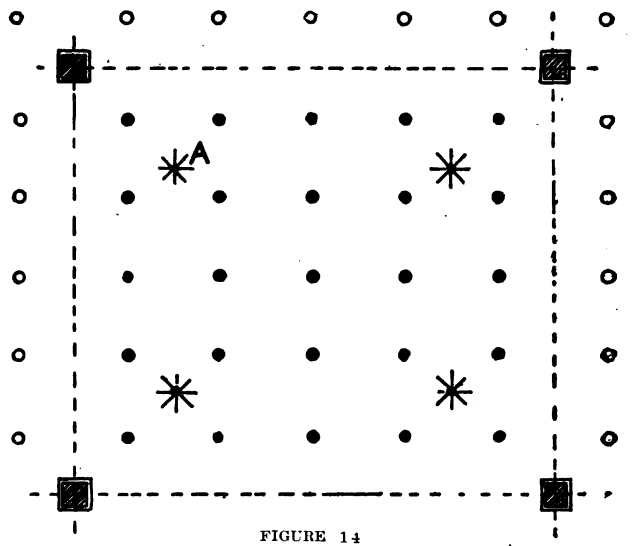

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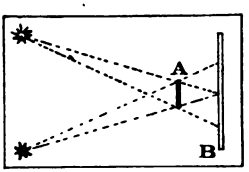

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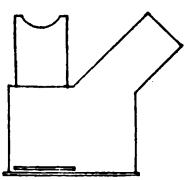

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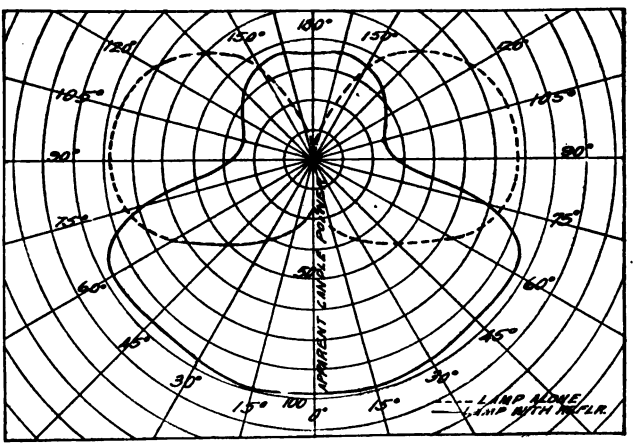

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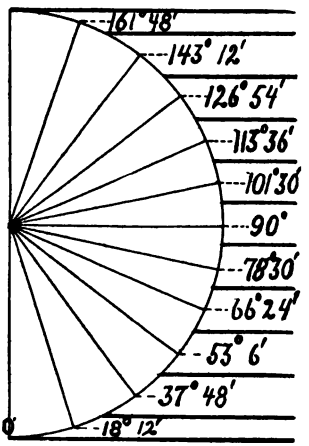

FIGURE 18

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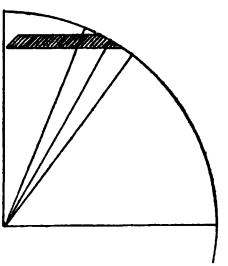

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ted in a zone governed by that degree, and if this be done for each degree and all of these sums added we shall have the total number of lumens given out by the lamp. It will seldom be necessary to carry the calculations to this degree of refinement in ordinary practical work, so that it is not assumed that the column here described will be much used for calculations of total lumens. It will, however, be of value in such zones where the intensity varies rapidly so that it is difficult to determine average values easily.

For more rapid and less exact calculations the columns headed by 5, 10 and 15 may be used. In each of these columns the area of a zone covering the corresponding number of degrees is given together with the degree number at which the candle power of the lamp in question must be read. Thus, for instance, if we wish to determine the number of lumens given off within a zone bounded by 165 to 161 degrees inclusive we read the intensity along 163 and multiply it by .1645, which is the area of the zone covered by those degrees. We may proceed in a similar way to find the lumens emitted in any other zone, and if the intensity is fairly even we may take zones of 10 or 15 degrees.

TABLE I

| Angle | Area | | |

CHAPTER VI

ILLUMINATION CALCULATIONS

Light, if unobstructed, radiates from its source in straight lines and in all directions. The quantity emitted from a given source remains unchanged by distance, with exception of a slight absorption by dust in the air. The intensity of the light must, therefore, decrease exactly in the same proportion as the area over which it spreads increases. This can readily be seen by reference to Figure 20, in which I is the source of light and the rays from it pass through the opening in a section of a sphere shown at 1 and project upon a section of a larger sphere at 2. By measuring the distance from 1 to various points along the four lines which represent the boundary of the ray and also measuring the space covered by the illumination we can readily see that the spaces at 1 and 2 and at any other point we may select are exactly proportional to the square of the distance from the point I, which is the source of the ray or rays. As the area over which a given quantity of light is spread increases as the square of the distance the intensity of the light must correspondingly decrease, and we obtain thus the law that, "the intensity of light is inversely proportional to the

square of the distance of the point illuminated from the source of illumination." In order that this law may be rigidly correct, the distances under consideration must be great enough so that the source of light may be considered as a mathematical point, i. e., possess no physical dimension, and the plane illuminated must be exactly at right angles to the rays.

For all practical purposes, however, the law holds

FIGURE 20

if the distance from the light is from ten to 15 times the apparent size of the source.

In the figure the surfaces affected by the rays of light are shown as sections of spheres and it is only in connection with such surfaces that the law is rigidly true, but here also, unless the surfaces are very large compared to the source, no error of any consequence will be introduced if the surface be perfectly flat, so long as it is placed at right angles to the rays.

If now, however, we consider a plane which is not at right angles to the ray, such as outlined by the lines 3, 4, 5 and 6 for instance, we see that the law of inverse squares is no longer applicable, as the surface illuminated no longer forms a square, the points 4 and 6 being at different distances from the source, the expansion of the light is different. Viewed from

above, the surface covered by the light assumes the shape indicated by the heavy lines at the right of Figure 21. If we now take the average distance from the source the law of squares still holds for the average width of the surface but not for the length.

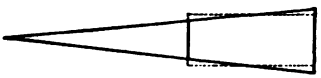

FIGURE 21

To determine the relation of the length of the surface to the incline of the surface we consult Figure 22. If we assume the ray of light to have the physical dimensions enclosed by the dotted lines, we can see that it spreads over a certain part of the base line bounded by the two dotted lines and that this is

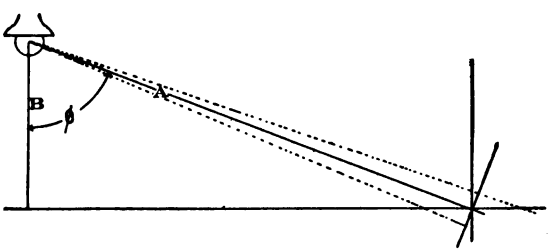

FIGURE 22

greater than the space covered on the line normal or at right angles to the center line of the ray. The ratio of the one to the other is proportional to the cosine of the angle between the lines A and B and in order to find the intensity of the illumination upon a horizontal surface, not directly under the lamp, we

must multiply the candle power at that particular degree by the cosine of the angle between the vertical line B and the ray or line A.

The fundamental formula for the calculation of illumination from a given lamp is $E=\frac{I}{l^{2w}}$ where E equals the intensity in foot candles, I the candle power of the lamp in a given direction and l the distance in feet from the lamp to the plane illuminated. This formula applies only so long as the plane to be illuminated is at right angles to the rays of light, or what is sometimes termed normal illumination.

To obtain the intensity of illumination on a horizontal plane, the formula is $E_h=\frac{I}{l^2}\cos \emptyset$ where $\emptyset$ is the angle between the ray of light and a vertical line through the lamp.

In order to avoid finding the length of l which is quite troublesome, it is customary to use the formula $E_h=\frac{I}{H^2}\cos^3 \emptyset$, H being the height of the lamp above the plane to be illuminated. The mathematical derivation of this formula need not be explained, it being sufficient to state that it is in general use.

To find the candle power necessary to give a certain intensity of illumination the above-mentioned formulae are transposed and we have $I = E_h\frac{l^2}{\cos \emptyset}$

and $I = E_h \frac{H^2}{\cos^3 \emptyset}$

The formula for calculating the intensity of illumination on a vertical plane is $E_v = \frac{I}{l^2} \sin \emptyset$ which can be changed in the same manner as above to $E_v = \frac{I}{D^2} \sin^3 \emptyset$, where D is the horizontal distance in feet from the center of the lamp to the plane illuminated.

When transposed to find the candle power required to produce a certain intensity this formula becomes $I = E_v \frac{l^2}{\sin \emptyset}$ or $I = E_v \frac{D^2}{\sin^3 \emptyset}$

The values of $\sin \emptyset$, $\cos \emptyset$, $\sin^3 \emptyset$ and $\cos^3 \emptyset$ are given in table No. II.

In all of these formulae the square of the distance of the point under consideration from the lamp plays an important part and it becomes necessary to warn against the indiscriminate use of this factor in illumination calculations. Aside from the limitations pointed out above there is another which must always be borne in mind. The law of inverse squares does not hold true where any of the rays from a given source are reflected to assist the illumination from the direct rays. Such is the case in a room where there are several lights and where the room is small enough to permit of reflection from walls or where, as in inverted lighting, the light is thrown first against the ceiling.

The only fairly accurate method (neglecting reflection) of calculation for illumination in ordinary places is what is known as the point by point method. To work by this method it is necessary first to obtain

TABLE II

Angle ø	Sin ø	Cos ø	$\sin^3$ ø	$\cos^3$ ø	Angle ø	Sin ø	Cos ø	$\sin^3$ ø	$\cos^3$ ø
0	.000	1.00	.0000	1.000	45	.707	.707	.353	.353
1	.018	.999	.0000	.999	46	.719	.695	.372	.335
2	.035	.999	.0000	.998	47	.731	.682	.391	.317
3	.052	.998	.0001	.996	48	.743	.669	.410	.299
4	.070	.997	.0003	.993	49	.755	.656	.430	.282
5	.087	.996	.0007	.988	50	.766	.643	.449	.265
6	.105	.995	.0012	.983	51	.777	.629	.469	.249
7	.122	.993	.0018	.978	52	.788	.616	.489	.233
8	.139	.990	.0027	.971	53	.799	.602	.509	.218
9	.156	.988	.0038	.963	54	.809	.588	.529	.203
10	.174	.985	.0052	.955	55	.819	.574	.550	.189
11	.191	.982	.0069	.946	56	.829	.557	.570	.175
12	.208	.978	.0090	.936	57	.839	.545	.590	.161
13	.225	.974	.0114	.925	58	.848	.530	.610	.149
14	.242	.970	.0142	.913	59	.857	.515	.630	.137
15	.259	.966	.0173	.901	60	.866	.500	.650	.125
16	.276	.961	.0209	.888	61	.875	.485	.669	.114
17	.292	.956	.0250	.874	62	.883	.469	.688	.103
18	.309	.951	.0295	.860	63	.891	.454	.707	.0936
19	.326	.946	.0345	.845	64	.899	.438	.725	.0843
20	.342	.940	.0400	.830	65	.906	.423	.744	.0755
21	.358	.934	.0460	.814	66	.914	.407	.762	.0673
22	.375	.927	.0526	.797	67	.920	.390	.780	.0596
23	.391	.920	.0596	.780	68	.927	.375	.797	.0526
24	.407	.914	.0673	.762	69	.934	.358	.814	.0460
25	.426	.906	.0755	.744	70	.940	.342	.830	.0400
26	.438	.899	.0843	.725	71	.946	.326	.845	.0345
27	.454	.891	.0936	.707	72	.951	.309	.860	.0295
28	.469	.885	.103	.688	73	.956	.292	.874	.0250
29	.485	.875	.114	.669	74	.961	.276	.888	.0209
30	.500	.866	.125	.650	75	.966	.259	.901	.0173
31	.515	.857	.137	.630	76	.970	.242	.913	.0142
32	.530	.848	.149	.610	77	.974	.225	.925	.0114
33	.545	.839	.161	.590	78	.978	.208	.936	.0090
34	.559	.829	.175	.570	79	.981	.191	.946	.0069
35	.574	.819	.189	.550	80	.985	.174	.955	.0052
36	.588	.809	.203	.529	81	.988	.156	.963	.0038
37	.602	.799	.218	.509	82	.990	.139	.971	.0027
38	.616	.788	.233	.489	83	.993	.122	.978	.0018
39	.629	.777	.249	.469	84	.995	.105	.983	.0012
40	.643	.766	.265	.449	85	.996	.087	.988	.0007
41	.656	.755	.282	.430	86	.998	.070	.993	.0003
42	.669	.743	.299	.410	87	.999	.052	.996	.0001
43	.682	.731	.317	.391	88	.999	.035	.998	.0000
44	.695	.719	.335	.372	89	.999	.017	.999	.0000

a curve showing the intensity existing at different points below some suitable lamp and reflector. The manner in which such curves are obtained is explained in chapter on Photometry and need not be discussed here.

We may take for the purpose of illustration one of the tables which have been prepared from such curves. Table III shows illumination obtainable from 25, 40 and 60 watt Mazda lamps with Holophane reflectors intensive type at different heights and distances from a point directly beneath the lamp. Suppose we wish to find the illumination obtainable

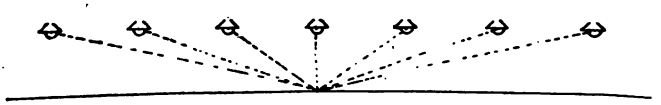

FIGURE 23

from 25-watt lamps arranged in one row and spaced 6 feet apart and 4 feet above the surface illuminated. The total illumination directly beneath lamp 1, Figure 23, will be the sum of the illumination directly beneath that lamp as given in Table III under O, plus the contribution from one light on each side given in the table under 6 feet, plus the contribution of two more lamps 12 feet from the center plus the contribution from the last lights 18 feet from the center. Adding all of these we have

1	at	0 feet	=	1.94
2	at	6 feet	=	.38
2	at	12 feet	=	.04
2	at	18 feet	=	.02
				2.38

which is the total illumination from 7 lamps arranged in one row spaced 6 feet apart and 4 feet above the plane to be illuminated. If we care to test the evenness of the illumination we can do so by the

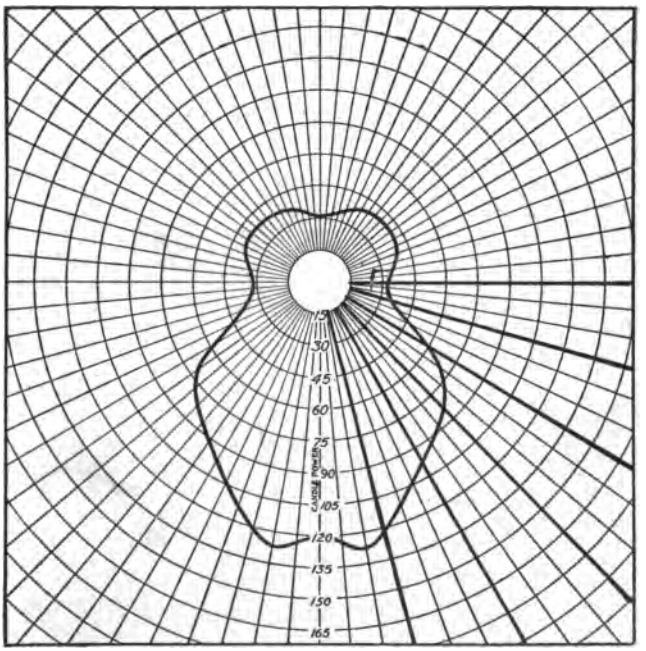

FIGURE 24

same method, taking the distance from the point between lamps to be considered to the different lamps.

In working from a curve in this manner we must first prepare a table similar to Table III, but, of course, it is not necessary to carry it out for any distances except those we are likely to consider.

TABLE NO. III.

Showing illumination in foot-candles from "Mazda" 25, 40, and 60-Watt, 100-125 volt, bowlfrosted lamps, equipped respectively with Holophane intensive clear high efficiency reflectors Nos. 106125, 106130, and 10615 (Top number in each space corresponds to the 25-watt, middle number to the 40-watt, and bottom number to the 60-watt unl.)

Horizontal distance of point investigated in feet from point directly beneath unit.

Height of unit in feet above plane to be illuminated.	0	1	2	3	4	5	6	7	8	9	10
4	1.94	1.77	1.34	0.87	0.51	0.30	0.19	0.11	0.07	0.05	0.04
	3.69	2.73	2.15	1.46	0.77	0.44	0.25	0.15	0·10	0.07	0.05
	5.40	4.78	3.64	2.39	1.22	0.70	0.38	0.22	0.14	0.10	0.07
5	1.24	1.17	0.97	0.73	0.50	0.33	0.22	0.14	0.10	0.07	0.05
	1.96	1.81	1.56	1.21	0.83	0.50	0.30	0.20	0.14	0.09	0.06
	3.46	3.20	2.69	2.05	1.33	0.78	0.48	0.31	0.20	0.12	0.09
6	0.87	0.83	0.73	0.59	0.45	0.33	0.23	0.16	0.11	0.08	0.06
	1.36	1.29	1.16	0.95	0.71	0.54	0.35	0.24	0.16	0.11	0.08
	2.40	2.26	1.98	1.62	1.23	0.87	0.54	0.36	0.25	0.17	0.11
7	0.64	0.62	0.56	0.48	0.39	0.30	0.22	0.17	0.12	0.09	0.07
	1.00	0.96	0.89	0 76	0.64	0.50	0.36	0.25	0.20	0.12	0.09
	1.76	1.69	1.55	1.29	1.07	0.81	0.59	0.40	0.29	0.19	0.14
8	0.49	0.48	0.44	0.39	0.34	0.27	0.21	0.17	0.13	0.10	0.08
	0.77	0.75	0.70	0.62	0.54	0.43	0.36	0.28	0.21	0.15	0.11
	1.35	1.31	1.22	1.07	0.92	0.74	0.59	0.45	0.33	0.23	0.17
9	0.38	0.37	0.35	0.33	0.28	0.24	0 19	0.16	0.13	0.10	0.08
	0.60	0.59	0.56	0.51	0.46	0.40	0 33	0.27	0.21	0.17	0.12
	1.08	1.04	0.98	0.88	0.79	0.68	0 55	0.44	0.33	0.26	0.18
10	0.31	0.31	0.29	0.27	0.25	0.21	0.18	0.15	0.14	0.10	0.08
	0.49	0.48	0 46	0.44	0.39	0.35	0.30	0.25	0.21	0.17	0.13
	0.87	0.84	0 81	0.74	0.68	0.59	0.51	0.41	0.33	0.27	0.21
11	0.26	0.26	0.25	0.23	0.21	0.19	0.17	0.14	0.12	0.10	0.08
	0.40	0.40	0.38	0.37	0.34	0.30	0.27	0.23	0.20	0.17	0.14
	0.71	0.69	0.67	0.63	0.58	0.51	0.45	0.39	0.33	0.27	0.22
12	0.21	0.21	0.20	0.19	0.19	0.17	0.15	0.13	0.11	0.10	0.08
	0.34	0.34	0.33	0.31	0.29	0.27	0.24	0.22	0.19	0.16	0.13
	0.60	0.59	0.57	0.54	0.50	0.46	0.40	0.36	0.31	0.26	0.21
13	0.19	0.19	0.18	0.17	0.16	0.15	0.13	0.12	0.10	0.09	0.08
	0.29	0.29	0.28	0.27	0.25	0.24	0.22	0.19	0.17	0.15	0.13
	0.51	0.50	0.49	0.47	0.44	0.41	0.37	0.32	0.29	0.25	0.21
14	0.16	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.08
	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.18	0.16	0.14	0.12
	0.44	0.43	0.42	0.41	0.38	0.36	0.33	0.30	0.27	0.24	0.20
15	0.14	0.14	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.07
	0.22	0.22	0.21	0.21	0.20	0.18	0.17	0.16	0.15	0.13	0.12
	0.38	0.38	0.37	0.36	0.34	0.32	0.30	0.27	0.25	0.23	0.20
16	0.12	0.12	0.12	0.12	0.11	0.10	0.10	0.09	0.08	0.08	0.07
	0.19	0.19	0.19	0.18	0.17	0.16	0.16	0.15	0.14	0.13	0.11
	0.34	0.33	0.32	0.31	0.30	0.28	0.27	0.25	0.23	0.21	0.19
17	0.11	0.11	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.07	0.06
	0.17	0.17	0.17	0.16	0.16	0.15	0.14	0.13	0.13	0.12	0.11
	0.30	0.29	0.29	0.28	0.27	0.26	0.24	0.23	0.22	0.20	0.18
18	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.06
	0.15	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.10
	0.27	0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.18	0.17
19	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06
	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.10	0.09
	0.24	0.24	0.24	0.23	0.22	0.21	0.20	0.19	0.18	0.17	0.16
20	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.06	0.05
	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.09	0.09
	0.22	0.22	0.21	0.21	0.20	0.19	0.18	0.17	0.17	0.16	0.15

TABLE NO. III

Showing Illumination in Foot-Candles from "MAZDA" 25, 40, and 60-Watt, 100-125 Volt, Bowl-Frosted Lamps, equipped respectively with Holophane Intensive Clear High Efficiency Reflectors Nos. 106125, 106130, and 106150. (Top number in each space corresponds to the 25-watt, middle number to the 40-watt, and bottom number to the 60-watt Unit.)

Horizontal distance of point investigated in feet from point directly beneath unit.

Height of unit in feet above plane to be illuminated.

	11	12	13	14	15	16	17	18	19	20
4	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	....
	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01
5	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
	0.07	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01
6	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	0.06	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
	0.09	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01
7	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01
	0.07	0.06	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01
	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02
8	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01
	0.09	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01
	0.13	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02
9	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01
	0.09	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.02	0.02
	0.15	0.10	0.08	0.07	0.05	0.04	0.03	0.03	0.02	0.02
10	0.07	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01
	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02
	0.16	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02
11	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01
	0.11	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02
	0.17	0.13	0.11	0.09	0.07	0.06	0.04	0.04	0.03	0.03
12	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01
	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.02
	0.17	0.15	0.11	0.09	0.07	0.06	0.05	0.04	0.04	0.03
13	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02
	0.11	0.09	0.08	0.07	0.06	0.04	0.04	0.03	0.03	0.02
	0.18	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.04
14	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02
	0.11	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.03
	0.18	0.15	0.13	0.11	0.09	0.07	0.06	0.05	0.04	0.04
15	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02
	0.11	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.03
	0.18	0.15	0.13	0.11	0.09	0.08	0.07	0.05	0.05	0.04
16	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02
	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03
	0.16	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.04
17	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02
	0.10	0.09	0.07	0.07	0.06	0.05	0.05	0.04	0.03	0.03
	0.16	0.14	0.12	0.11	0.10	0.09	0.07	0.06	0.05	0.05
18	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02
	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.03
	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.06	0.06	0.05
19	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02
	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03
	0.15	0.13	0.12	0.10	0.10	0.09	0.08	0.07	0.06	0.05
20	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02
	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03
	0.14	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.06	0.05

In Table IV we have all the data necessary for the rapid preparation of such tables and to prepare them it is but necessary to multiply the candle power found in any curve at any degree by the number given in table at corresponding degree. The result will be the illumination at corresponding heights and distance from lamp.

Example: We wish to find the illumination obtainable from the lamp, a curve of which is shown in Figure 24, at 2, 4 and 6 feet from lamp and with the lamp 6 feet above plane to be illuminated. From Table IV we see that we must read the curve at 18 degrees and multiply the candle power given by .02372 to obtain the intensity at 2 feet from point directly beneath lamp; for 4 feet distance we read the curve at 33 degrees 42 minutes where we find .01600 and at 6 feet we have 45 degrees and .00982. The intensity at 18 degrees is about 115, which multiplied by .02372, gives us an intensity of 2.73 foot candles. At 33 degrees, the intensity is about 95 which multiplied by .01600 gives us 1.52 foot candles.

The intensity at 6 feet is found in the same manner.

By the above method we can obtain very accurate results if we carry the calculations far enough and it is merely a question of labor to determine the illumination at any point. The illumination obtained by the calculations above will, however, be always increased more or less by reflected light from walls and ceilings, and there is no way in which this can be very accurately determined. The proportional amount of reflected light will vary with the size of

TABLE NO. IV

Intensity of Illumination in Foot-Candles on Horizontal Planes at Points at Various Distances from a Light Source of 1 Candle-Power. Angle Between Light Ray and Line Perpendicular to Plane Illuminated

Horizontal distance in feet from point directly under light source to point where intensity of illumination is desired.

Height of light source in feet above plane illuminated.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4	0° 0′ .06250	14° 2′ .05707	26° 34′ .04472	36° 52′ .03200	45° 0′ .02210	51° 20′ .01524	56° 19′ .01066	60° 15′ .00764	63° 26′ .00559	66° 2′ .00419	68° 12′ .00320	70° 1′ .00249	71° 34′ .00198	72° 54′ .00159	74° 3′ .00130	75° 4′ .00107	75° 56′ .00090	76° 46′ .00075	77° 28′ .00064	78° 7′ .00055	78° 42′ .00047
5	0° 0′ .04000	11° 19′ .03771	21° 48′ .03202	30° 58′ .02522	38° 40′ .01904	45° 0′ .01414	50° 11′ .01050	54° 28′ .00785	58° 0′ .00595	60° 57′ .00458	63° 26′ .00358	65° 24′ .00283	67° 23′ .00228	68° 58′ .00185	70° 21′ .00152	71° 34′ .00126	72° 39′ .00106	73° 37″ .00090	74° 29′ .00077	75° 15′ .00066	75° 56′ .00057
6	0° 0′ .02778	9° 28′ .02673	18° 26′ .02372	26° 34′ .01987	33° 42′ .01600	39° 48′ .01260	45° 0′ .00982	49° 24′ .00766	53° 8′ .00600	56° 19′ .00474	59° 3′ .00378	61° 23′ .00305	63° 26′ .00249	65° 13′ .00205	66° 48′ .00170	68° 12′ .00142	69° 27′ .00120	70° 34′ .00102	71° 34′ .00088	72° 28′ .00076	73° 18′ .00066
7	0° 0′ .02041	8° 8′ .01980	15° 57′ .01814	23° 12′ .01585	29° 45′ .01336	35° 32′ .01100	40° 37′ .00893	45° 0′ .00722	48° 49′ .00582	52° 7′ .00473	55° 1′ .00385	57° 31′ .00316	59° 45′ .00261	61° 41′ .00218	63° 26′ .00183	64° 59′ .00154	66° 23′ .00131	67° 37′ .00113	68° 45′ .00097	69° 46′ .00084	70° 43′ .00074
8	0° 0′ .01563	7° 8′ .01527	14° 2′ .01427	20° 33′ .01283	26° 34′ .01118	32° 0′ .00953	36° 52′ .00800	41° 10′ .00667	45° 0′ .00552	48° 22′ .00458	51° 20′ .00381	53° 59′ .00318	56° 19′ .00267	58° 24′ .00225	60° 15′ .00191	61° 55′ .00163	63° 26′ .00140	64° 48′ .00121	66° 2′ .00105	67° 10′ .00091	68° 12′ .00080
9	0° 0′ .01235	6° 20′ .01212	12° 32′ .01148	18° 26′ .01054	23° 55′ .00943	29° 3′ .00825	33° 42′ .00711	37° 52′ .00607	41° 38′ .00515	45° 0′ .00437	48° 0′ .00370	50° 42′ .00314	53° 8′ .00267	55° 18′ .00228	57° 15′ .00196	59° 3′ .00168	60° 38′ .00146	62° 6′ .00126	63° 26′ .00110	64° 40′ .00097	65° 46′ .00085
10	0° 0′ .01000	5° 43′ .00985	11° 19′ .00943	16° 42′ .00879	21° 48′ .00801	26° 34′ .00716	30° 58′ .00631	35° 0′ .00550	38° 40′ .00476	41° 59′ .00411	45° 0′ .00354	47° 43′ .00305	50° 11′ .00263	52° 26′ .00227	54° 28′ .00196	56° 19′ .00171	58° 0′ .00149	59° 32′ .00130	60° 57′ .00115	62° 14′ .00101	63° 26′ .00089
11	0° 0′ .00826	5° 12′ .00816	10° 18′ .00787	15° 15′ .00742	19° 59′ .00686	24° 27′ .00623	28° 37′ .00559	32° 28′ .00496	36° 2″ .00437	39° 17′ .00383	42° 16′ .00335	45° 0′ .00292	47° 30′ .00255	49° 46′ .00223	51° 50′ .00195	53° 45′ .00171	55° 30′ .00150	57° 6′ .00132	58° 34′ .00117	59° 56′ .00104	61° 12′ .00092
12	0° 0′ .00694	4° 46′ .00687	9° 28′ .00668	14° 2′ .00634	18° 26′ .00593	22° 37′ .00546	26° 34′ .00497	30° 15′ .00448	33° 42′ .00400	36° 52′ .00356	39° 48′ .00315	42° 31′ .00278	45° 0′ .00246	47° 17′ .00217	49° 24′ .00191	51° 20′ .00169	53° 8′ .00150	54° 49′ .00133	56° 19′ .00119	57° 43′ .00106	59° 3′ .00094
13	0° 0′ .00592	4° 24′ .00587	8° 45′ .00571	13° 0′ .00547	17° 6′ .00517	21° 2′ .00481	24° 46′ .00447	28° 18′ .00404	31° 34′ .00366	34° 42′ .00329	37° 34′ .00295	40° 14′ .00263	42° 44′ .00235	45° 0′ .00209	47° 6′ .00187	49° 5′ .00166	50° 54′ .00148	52° 36′ .00133	54° 10′ .00119	55° 38′ .00106	56° 59′ .00096
14	0° 0′ .00510	4° 5′ .00506	8° 8′ .00495	12° 6′ .00477	15° 57′ .00454	19° 39′ .00426	23° 12′ .00396	26° 34′ .00365	29° 45′ .00334	32° 44′ .00304	35° 32′ .00275	38° 9′ .00248	40° 37′ .00223	42° 53′ .00201	45° 0′ .00180	46° 58′ .00162	48° 49′ .00146	50° 31′ .00131	52° 7′ .00118	53° 37′ .00107	55° 1′ .00096
15	0° 0′ .00444	3° 49′ .00442	7° 36′ .00433	11° 19′ .00419	14° 56′ .00401	18° 26′ .00380	21° 48′ .00356	25° 1′ .00331	28° 4′ .00305	30° 58′ .00280	33° 42′ .00256	36° 15′ .00233	38° 40′ .00212	40° 55′ .00192	43° 1′ .00174	45° 0′ .00157	46° 51′ .00142	48° 34′ .00129	50° 11′ .00117	51° 43′ .00106	53° 8′ .00096
16	0° 0′ .00391	3° 35′ .00388	7° 8′ .00382	10° 37′ .00371	14° 2′ .00357	17° 25′ .00339	20° 33′ .00321	23° 38′ .00300	26° 34′ .00280	29° 23′ .00259	32° 0′ .00238	34° 30′ .00219	36° 52′ .00200	39° 6′ .00183	41° 10′ .00167	43° 9′ .00152	45° 0′ .00138	46° 45′ .00126	48° 22′ .00115	49° 53′ .00105	51° 20′ .00095
17	0° 0′ .00346	3° 22′ .00344	6° 42′ .00339	10° 0′ .00331	13° 15′ .00319	16° 24′ .00306	19° 26′ .00290	22° 23′ .00274	25° 12′ .00256	27° 54′ .00239	30° 28′ .00222	32° 54′ .00205	35° 13′ .00189	37° 24′ .00174	39° 29′ .00159	41° 25′ .00146	43° 16′ .00134	45° 0′ .00122	46° 38′ .00112	48° 11′ .00103	49° 39′ .00094
18	0° 0′ .00309	3° 11′ .00307	6° 20′ .00303	9° 28′ .00297	12° 32′ .00287	15° 32′ .00276	18° 26′ .00264	21° 14′ .00250	23° 55′ .00236	26° 34′ .00221	29° 3′ .00206	31° 26′ .00192	33° 42′ .00178	35° 49′ .00165	37° 52′ .00152	39° 48′ .00140	41° 38′ .00129	43° 22′ .00119	45° 0′ .00109	46° 33′ .00100	48° 0′ .00092
19	0° 0′ .00277	2° 1′ .00276	6° 0′ .00273	8° 58′ .00267	11° 53′ .00260	14° 45′ .00251	17° 31′ .00240	20° 13′ .00229	22° 50′ .00217	25° 21′ .00205	27° 45′ .00192	30° 4′ .00180	32° 17′ .00167	34° 23′ .00156	36° 23′ .00145	38° 17′ .00134	40° 6′ .00124	41° 49′ .00115	43° 27′ .00106	45° 0′ .00098	46° 29′ .00090
20	0° 0′ .00250	2° 53′ .00249	5° 43′ .00246	8° 32′ .00242	11° 19′ .00236	14° 2′ .00228	16° 42′ .00219	19° 17′ .00210	21° 48′ .00200	24° 14′ .00190	26° 34′ .00179	28° 49′ .00168	30° 58′ .00158	33° 2′ .00147	35° 0′ .00137	36° 52′ .00128	38° 40′ .00119	40° 22′ .00111	41° 59′ .00103	43° 32′ .00095	45° 0′ .00088

rooms; the type of unit employed; the height of suspension; and the color of walls and ceilings. The following table gives the percentage of light reflected by various materials.

Material	Percent light reflected
Highly polished silver	92
Mirror silvered on back	70 to 85
White blotting paper	82
White cartridge paper	80
Highly polished brass	70 to 75
Mirror backed with amalgam	70
Ordinary foolscap paper	70
Highly polished copper	60 to 70
Highly polished steel	60
Burnished copper	40 to 50
Chrome yellow paper	60
Orange paper	50
Yellow wall paper	40
Yellow painted wall	40
Light pink paper	35
Yellow card board	30
Light blue wall paper	25
Brown card board	20
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Bluish green paper	12
Cobalt blue paper	12
Black paper	5
Deep chocolate paper	4
Black cloth	1.2
Black velvet	0.4

If only a single lamp covered by reflector in a large room with dark walls and floor is used, there will be no appreciable reflection. With an extensive reflector or bare lamp in small light room, the reflected light may more than double the calculated light.

The following table taken from publications of the Holophane Company and based upon experiments made by them with holophane reflectors will be of use in connections with point by point methods of calculating illumination. It must be borne in mind that holophane reflectors allow a portion of the light to pass to the ceiling and, therefore, the effect of reflected light is greater than with opaque reflectors such as metal or mirrors.

This table applies only to small or medium size rooms. In large spaces the effect will be less.

Condition of ceiling	Condition of walls	Increase over calculated illumination
Very dark	Very dark	0%
Medium	Very dark	15%
Medium	Medium	40%
Very light	Very dark	30%
Very light	Medium	55%
Very light	Very light	80%

The point by point method is valuable only in connection with fairly low ceilings and conditions such as are found in industrial institutions, shipping rooms, department stores, etc. For calculating the illumination of churches, theatres, assembly halls and other places of often irregular shape and height, a

different method must be employed. In such places part of the illumination is generally obtained from center chandeliers and from lights studded about the walls or fronts of galleries. The lamps are often so mounted as to throw the light in different directions.

The simplest and best formula for this class of buildings is the following: Multiply the floor area to be lighted by the intensity in foot candles desired and divide by the effective lumens of the lamps under consideration.

$$\frac{\text{Area in square feet} \times \text{intensity in foot candles}}{\text{Per cent of lumens effective}} = \text{Lumens required}$$

The lumens per lamp may be taken from table and by dividing the total lumens required by the number of lumens per lamp the necessary number of lamps can be found. The lumens per lamp generally equal the horizontal candle power multiplied by a spherical reduction factor. This factor for metal filament lamps is generally taken as 0.78 and for graphitized or carbon filament lamps as 0.82. These figures will bring it near enough for all practical purposes.

In the following table are given the percentage of lumens effective under different conditions. The total lumens obtainable from any type of lamp must be multiplied by this percentage to find the effective lumens of lamp.

These figures apply to ordinary rooms and for lamps hung at ordinary heights.

With Prismatic Reflectors

Very light walls and ceilings.....60 to 65%
Light walls and ceiling.....55 to 60%
Light ceiling and dark walls.....45 to 50%
Dark walls and ceiling.....35 to 40%

Bare Lamps

Very light walls and ceiling.....40 to 45%
Light walls and ceiling.....35 to 40%
Light ceiling and dark walls.....25 to 30%
Dark walls and ceiling.....10 to 20%

With Opal Glass Reflectors

Very light walls and ceiling.....55 to 60%
Light walls and ceiling.....50 to 55%

For Indirect Lighting

Light ceiling and walls.....35%
Light ceiling and medium walls.....30%
Light ceiling and dark walls.....25%

Indirect lighting is not feasible with dark ceilings.

The "point by point" method has the fault that the value of reflection cannot be properly or accurately determined and where there are many lights acting upon each other as in large spaces illuminated by several rows of lamps too much variation is given on account of height. In the original lamp on which calculations are based and considered entirely by itself neglecting reflection, the intensity under the lamp varies exactly as the square of the distance. This, we have seen, is due entirely to the fact that

the light spreads over an area increasing as the square of the distance. If the light could be confined to a certain area either by direct reflectors which keep it within certain bounds or by reflection from walls and ceilings the intensity would be independent of the height. It would be weakened then only by absorption. It is to account for this error, as well as the fact that the reflected light is omitted from the calculations, that the correction factors ranging from 0 to 80% have been supplied.

The other method which is known as "The flux of light method" is at fault in that it does not take into consideration the height and gives no idea of the evenness of illumination. We learn from it only that we must have a certain number of lumens in order to provide a certain intensity of illumination. This method can be used with good results only by persons of considerable experience and requires considerable study as to the manner in which the quantity of light, which we learn from the formula must be used, is to be divided. It is really of no use unless accompanied to some extent by point by point calculations or their equivalent.

Table following is prepared with a view of showing under which circumstances the point by point method and the flux of light method calculations give identical results and also such conditions where they do not. The table has been calculated for 60-watt mazda or tungsten lamps and shows in the lines marked "Square feet" the number of square feet a 60-watt lamp will illuminate with the intensity in foot candles given directly above it under the con-

ditions of ceilings and walls noted in the same vertical column.

The constants given in top row are those given by the engineers of the Holophane Company for use with the two methods respectively. For the point by point method the results obtained are to be increased by the per cent given to obtain effect of reflection which is neglected in these calculations. Thus, with ceilings and walls dark, using one row of 60-watt tungsten lamps 6 feet apart and 5 feet above plane illuminated, we obtain 4.5 foot candles. In the next column we have light ceiling and dark walls and add 30% to 4.5, which gives us 5.85 foot candles.

For the flux of light method we have transposed the original formula by which we determine the number of lumens required to illuminate a certain area so as to find the area a given number of lumens will illuminate. The formula is:

$$\text{Area} = \frac{\text{lumens} \times \text{constant}}{\text{Intensity}}$$

A 60-watt lamp gives 500 lumens; this multiplied by .38 equals 190; this divided by the intensity, 4.5, which is used to make the comparison simple, gives 42 square feet as the area which would be illuminated to that degree, whereas by the point by point method we have only 36 square feet.

The illumination considered in both cases is given as the average illumination, but it must be noted that in the case of one row from which the point by point calculations are made the average illumination is not the average over the whole area but the average in

Table Illustrating Discrepancies Between "Point by Point" and "Flux of Light" Methods of Calculating Illumination

Constants			Point by Point Method			Flux of Light Method		
			0	.30	.80	.38	.45	.57
	Height	Condition of Ceiling Condition of Walls	Very Dark Very Dark	Very Light Very Dark	Very Light Very Light	Dark Dark	Light Dark	Light Light
1 Row	5 Ft.	Avrg. Ft. Candles Square Feet	4.5 36	5.85 36	8.10 36	4.5 42	5.85 38	8.1 35
	12 Ft.	Avrg. Ft. Candles Square Feet	1.8 36	2.34 36	3.24 36	1.8 105	2.34 96	3.24 88
2 Rows	5 Ft.	Avrg. Ft. Candles Square Feet	5.6 36	7.28 36	10.08 36	5.6 34	7.28 31	10.08 28
	12 Ft.	Avrg. Ft. Candles Square Feet	3.2 36	4.16 36	5.76 36	3.2 59	4.16 54	5.76 49
3 Rows	5 Ft.	Avrg. Ft. Candles Square Feet	6.3 36			6.3 31	6.3 35	6.3 45
	12 Ft.	Avrg. Ft. Candles Square Feet	4.3 36			4.3 44	4.3 52	4.3 66
4 Rows	5 Ft.	Avrg. Ft. Candles Square Feet	6.6 36			6.6 29	6.6 34	6 6 43
	12 Ft.	Avrg. Ft. Candles Square Feet	5.0 36			5.0 38	5.0 44	5.0 57

Area = $\frac{\text{lumens} \times \text{con't}}{\text{Intensity}}$

60 watt lamp = 500 lumens

Point by point foot candles taken from tables.

a straight line directly under the lamps and between them. The average over the whole area would be somewhat less and thus still more increase the discrepancy.

We can see from the above demonstration that both methods are but approximations and that there are certain conditions under which one or the other may be relied upon and still other conditions under which both may be used as a check on each other. In any case, however, experience is of the greatest value and absolutely necessary to secure good results.

In all cases of complicated lighting it is best to calculate for high intensity and arrange circuits so that there will be considerable leeway. The candle power of lamps can then be varied to suit the needs of the service. This, of course, is not very economical, but it is the only safe way where good results are to be obtained.

CHAPTER VII

CHARACTERISTICS OF ELECTRIC ILLUMINANTS—OPEN-ARC LAMPS—DIRECT CURRENT ON SERIES CIRCUITS

Systems With Which They May be Used.—These lamps are always operated either from a series dynamo or a mercury arc rectifier. In the latter case they are operated in connection with alternating current primaries.

Principal Uses.—These lamps are used for street lighting and also often for the illumination of large open spaces or sheds.

Voltage.—When run on series circuits each lamp will require about 50 volts.

Current.—They are made in two sizes, the so called full arc which is nominally rated at 2,000 candle power requiring from 9.6 to 10 amperes and the half arc nominally rated at 1,200 candle power which operates at from 6.5 to 7 amperes.

Color of Light.—The light is bluish white or nearly white in color and fairly well suited for color matching being superior to the enclosed arc in this respect.

Natural Distribution of Light.—The point of maximum intensity of illumination is 45 degrees below the horizontal.

Efficiency.—The efficiency is 1.2 to 1.3 watts mean

spherical candle power or 0.8 to 0.9 per lower hemispherical candle power.

This efficiency is based upon the use of clear globes but clear globes are useful only where very large areas are to be illuminated.

Life of Carbons.—12 to 14 hours.

Advantages.—The series arc lamp is now almost obsolete. Its principal advantage is to be found in first cost of line construction. It can be recommended only in connection with existing circuits.

General Objections.—The objectionable features are: Unsteady light; very strong shadows; frequent trimming; many lights liable to be out at the same time; large fire and life hazard; high intrinsic brilliancy causing damage to eyesight when used indoors.

DIRECT CURRENT; MULTIPLE CIRCUITS

Systems with which they may be Used.—The low tension arc lamp is generally used two in series on 110 or 120 volts, but a greater number may be operated with a corresponding increase in voltage. If only one lamp is to be operated, considerable resistance must be placed in circuit with it. Resistances must also be used with any number of lamps.

Principal Uses.—This lamp is used for outside lighting and indoors, but principally for large areas or where a very strong light is wanted as for photography or stage lighting.

Voltage.—The voltage across the arc is about 45 and sufficient resistance must be placed in series with the lamp to take up the excess voltage of the circuit.

Current.—The range of current is about the same as with the series arc lamp, 6 to 10 amperes.

Color of Light.—The light is suitable for color matching and superior to the enclosed arc in this respect.

Natural Distribution of Light.—The point of maximum intensity of illumination is the same as with the series arc, 45 degrees below the horizontal.

Efficiency.—The efficiency of the arc is the same as that of the series arc lamp, but owing to the fact that this lamp can operate only with extra resistance in circuit, not all of the energy is given to the arc. The total efficiency is therefore much lower than that of the series lamp and varies with the number of lamps operated in series.

Life of Carbons.—12 to 14 hours.

Recommendations Regarding Carbons.—A good grade of carbon is required and the positive carbon may be either cored or solid. The negative carbon is generally solid. Copper coated carbons should be avoided on account of fire hazard.

Advantages.—The hazard to life and from fire is much less with this lamp than with the high tension series lamp.

It has further the advantage that it can be made to operate with currents from 6 to several hundred amperes and lamps for stage lighting built for 50 amperes are not unusual.

A further advantage is that it can be used on all ordinary direct current lighting circuits.

The light is also more steady than that of the

series lamp and if fitted for hand feed, can be made very even and steady.

General Objections.—The objectional features are: Somewhat unsteady light; strong shadows; frequent trimming; high intrinsic brilliancy requiring use of frosted globes.

ALTERNATING CURRENT; SERIES CIRCUITS

Systems with Which They May Be Used.—These lamps are operated from alternating current circuits provided with suitable constant current regulators. Any number of such lamps may be run on one circuit. Not all lamps will operate well on frequencies as low as 25 cycles and none will operate with less.

Principal Uses.—The principal uses of this lamp are about the same as for the direct current series lamp. They are used mainly for street lighting and similar work.

Voltage.—About 40 volts are required for each lamp.

Current.—The current ranges from 10 to 15 amperes.

Color of Light.—The same as the direct current lamp; bluish white.

Natural Distribution of Light.—The light is not naturally thrown downward as much as with direct current lamps and reflectors should be used.

Efficiency.—The efficiency is much lower than that of the direct current lamp.

Life of Carbons.—Carbons last only from 8 to 12 hours and make frequent trimming necessary.

General Advantages.—This style of lamp is much

in favor for street and yard lighting. They can be operated on any alternating current circuit with a frequency of not less than 25 cycles. The distribution of light is well suited for street lighting.

General Objections.—This lamp requires frequent trimming; gives out a disagreeable humming sound; throws out strong shadows and all lights are liable to be out at the same time.

ALTERNATING CURRENT; MULTIPLE CIRCUITS

Systems with Which They May Be Used.—These lamps may be used with all alternating current systems suitable for the series lamps but no special regulators are required. They are generally connected two in series on 110 volt circuits, but more may be used with a corresponding increase in voltage. With these lamps reactances are used in the same manner as resistances with direct current arc lamps.

Principal Uses.—This lamp may be used outdoor or indoors where strong shadows are not objectionable. It is also used for stage lighting and photography.

Voltage.—The voltage of the alternating current arc is about 28 and reactance enough must be placed in circuit with it to take up the remainder.

Current Used.—The current ranges from 10 to 15 amperes in ordinary lamps, but special arcs are in operation carrying upward of 5,000 amperes.

Color of Light.—Bluish white.

Natural Distribution of Light.—The light is not naturally thrown downward as much as with direct current arc lamps and reflectors should be used.

Efficiency.—Owing to the low voltage used at the arc which makes necessary the dissipation of much energy on 110 volt circuits the efficiency of the lamp is probably the lowest of all arc lamps.

Life of Carbons.—Carbons last only from 8 to 12 hours and make frequent trimming necessary.

General Advantages.—This lamp can be recommended only where a very strong light is required and where the lamps are on hand. It is not advisable to put in a new installation.

General Objections.—High cost of energy, unpleasant humming, frequent trimming, unsteady light, high intrinsic brilliancy and strong shadows.

THE ENCLOSED ARC LAMP

Systems with Which They May Be Used.—These lamps may be operated on direct or alternating circuits and in series or multiple, but must be specially designed for circuits on which they are to be used. They are seldom operated at frequencies of less than 60 cycles.

Principal Uses.—They may be used for illumination anywhere where there is sufficient head room. They are not to be recommended for low ceilings or small areas.

DIRECT CURRENT LAMP ON SERIES CIRCUITS

Voltage.—The lamp requires from 75 to 80 volts and no resistances are necessary if operated from arc dynamo. They may be operated on high tension multiple circuits such as street railway and in this case they must be provided with resistances as in

straight multiple work. They may also be operated from alternating current circuits through the mercury arc rectifier.

Current Used.—The current varies from 6 to 6.6 amperes.

Rating in Candle Power.—The rating of this type of lamps is usually between 200 and 250 mean spherical candle power.

Color of Light.—The color of light is inferior to that of the open arc but may be modified and improved by the use of proper globes. The use of opal inner and outer globes improves the color and the distribution.

Natural Distribution of Light.—When clear globes are provided the point of maximum intensity is about 45 below the horizontal.

Efficiency.—The efficiency of series lamps is about 2 watts per spherical candle power when used with clear globes.

Life of Carbons.—A pair of carbons will last from 80 to 200 hours, depending upon the size of carbon and the current used.

Recommendations Regarding Carbons.—The use of cored carbons for the positive electrode tends to steady the arc.

General Advantages.—The light is more even and steady than that of the open arc. Very little ash is deposited. The labor of trimming is much reduced The fire hazard due to the lamp is almost nil. The first cost of wiring is low.

General Objections.—The general objections are: Hazard to life owing to the high voltage employed;

liability of all lamps giving out at the same time. Direct current series arc lighting is almost obsolete and not to be recommended except in connection with street railway circuits and old existing systems.

DIRECT CURRENT LAMP ON MULTIPLE CIRCUITS

Voltage.—Lamps are used singly on 110 or 120-volt circuits, but may be arranged in series with proportionate increase in voltage per lamp. The voltage across the arc is from 75 to 80. A lamp for 220 volt circuits is made but has not proven universally satisfactory. It requires a voltage of from 140 to 160 across the arc.

Current Used.—Lamps are made to operate with from 3 to 7 amperes, the larger current giving the best satisfaction. The lamps most in use take from 5 to 6 amperes.

Rating in Candle Power.—The candle power varies from 80 in some of the small lamps to 350 mean spherical candle power in the large current lamps.

Color of Light.—The color value of the 110 volt lamp is about the same as that of the series and inferior to the open arc.

The 220-volt lamp is much inferior in color value to the 110-volt lamp.

Natural Distribution of Light.—The point of maximum intensity is about 45 degrees below the horizontal.

Efficiency.—The efficiency is 2.2 to 3.5 watts per mean spherical candle power.

Life of Carbons.—The life of a pair of carbons is 80 to 200 hours.

General Advantages.—This lamp has the advantage over the series lamp that all are independent of each other. Trouble with one lamp will not interfere with other lamps. Life and fire hazard are much reduced. The cost of trimming is low.

General Objections.—The first cost of wiring is much greater than with series lamps. The energy required for lighting a given area is greater than with series lamps.

Practical Hints.—Limit lamps to one per circuit on 110 volts or 2 in series on 220. Use only double pole switches. Do not install where inflammable gases or dust exist.

ALTERNATING CURRENT LAMP ON SERIES CIRCUITS

Principal Uses.—This lamp is used mostly for street lighting purposes. It is connected by special transformer and regulator to the high tension circuits which distribute light and power.

Voltage Per Lamp.—The voltage required by series lamps is about 75 or 80.

Current Used.—The current is about 6.6 amperes.

Color of Light.—The color of the light is not very well adapted to color matching and is inferior to that of the open direct current arc. The light may be improved by the use of opal inner and outer globes.

Natural Distribution of Light.—The point of maximum intensity is about 60 degrees above and below the horizontal and equal in the upper and lower hemisphere. Reflectors should be used with these lamps.

Efficiency.—The efficiency is about 2.5 watts per mean spherical candle power.

Life of Carbons.—The life of a pair of carbons is 80 to 150 hours.

Recommendations Regarding Carbons.—The use of one cored carbon tends to steady the arc.

General Advantages.—The distribution of light is well suited to street illumination. The first cost of wiring is low. Lamps can readily be installed wherever alternating current circuits are available.

General Objections.—The alternating current arc lamp is noisy: all lamps are liable to be out at the same time; there is considerable fire and life hazard. The power factor is low and there is likely to be disturbance of other lights fed from the same mains.

ALTERNATING CURRENT LAMP ON MULTIPLE CIRCUITS

Principal Uses.—This lamp is used mainly for store lighting and similar work.

Voltage.—These lamps are connected singly in 110 volt circuits or 2 in series on 220. When used singly on 220 volts an extra reactance must be placed in series with the lamp.

Current Used.—The majority of enclosed lamps take from 5 to 6 amperes but lamps are obtainable for smaller currents.

Color of Light.—Like the direct current arc the color value is unfavorably affected by enclosing the arc.

Natural Distribution of Light.—The point of maximum intensity of illumination is about 60 degrees above and below the horizontal and ordinarily reflectors are required.

Efficiency.—The efficiency of this lamp is somewhat

lower than that of the direct current enclosed arc and may be taken as from 2.5 to 4 watts per mean spherical candle power.

General Advantages.—Suitability for use on almost all alternating current circuits where the frequency is not less than 60 cycles.

General Objections.—The general objections are disagreeable humming and low efficiency. These lamps are very little used at present.

THE INTENSIFIED ARC

This is one form of an enclosed arc. It uses small diameter carbons and a high current density. These lamps may be used with any system of electric lighting except constant current systems.

Principal Uses.—It may be used wherever the ordinary enclosed arc can be used and is especially useful in drygoods stores and other places where it is necessary to match colors, or where it is essential to have a light of good color value.

Voltage.—The voltage of the arc is about 80 volts and the lamp may be used singly on 110 volt circuits by placing resistance in series with it. Several lamps may be operated in series with a corresponding increase in voltage.

Current Used.—Lamps are made using from 3½ to 6 amperes but most of the lamps now in use take about 5 amperes. The efficiency of lamps using less than 5 amperes is not as good as that of the higher current.

Color of Light.—The color value of the light is better than that of any other electric light except that

of the Moore tube. A special type of lamp is made that is said to be equal to daylight for color matching

Natural Distribution of Light.—The general distribution of the light is good and it is mainly in the lower hemisphere.

Efficiency.—The efficiency is about 1 to 1.5 watts per mean lower hemispherical candle power.

Life of Carbons.—A pair of carbons will last from 80 to 100 hours.

Recommendations Regarding Carbons.—Special carbons must be used in connection with this lamp and these are somewhat more expensive than the ordinary carbons used with enclosed arc lamps.

General Advantages.—The color of the light and the distribution are very good.

THE FLAMING ARC LAMP

The flaming arc uses carbons impregnated with certain mineral salts. This causes the arc to become more luminous and also enables a longer arc to be maintained, both of which factors add to the efficiency.

The early types used the open arc with inclined carbons and the life of a pair of carbons was not over 12 or 18 hours. These lamps were not suitable for indoor use on account of the fumes and the ashes resulting from the burning carbons.

There are now several types on the market in which these objections have been overcome, principally by enclosing the arc, using a better grade of carbons and by using special methods of ventilating and collecting ashes.

Some makers avoid the necessity of frequent trimming by the use of magazines containing several sets of carbons or by using very long carbons. Both of these methods are, however, in many ways objectionable.

Systems They May Be Used With.—Lamps are made for use in connection with any system of electric lighting in commercial use but they are not interchangeable and must be ordered to fit the circuit requirements. They are better suited for low frequencies such as 25 cycles than any of the other arc lamps.

Principal Uses.—These lamps are of use only for the illumination of large areas, fronts of buildings, streets, etc., where large units can be used and where ceilings are not too low. They are used to some extent in the theatre lighting on stage as well as in auditorium. The yellowish light is particularly well suited for the illumination of foundries and similar places where there is much dust or vapor.

Voltage.—Most types of this lamp require about 45 volts across the arc and are ordinarily used two in series on 110 volt circuits, but there are types that can be connected 3 in series on 110 volts. Other types are used singly on 110 volts or 2 in series on 220 volts. Resistance must be used in each lamp.

Current Used.—Lamps are made taking from 6½ to 12 amperes.

Color of Light.—The color of the light depends upon the mineral salts used in connection with the carbons. The familiar golden color is obtained by the use of calcium. Other salts are used to obtain red or white light.

Natural Distribution of Light.—In the inclined carbon type the point of maximum intensity is directly under the lamp. When vertical carbons are used the point of maximum intensity is from 20 to 30 degrees below the horizontal.

Efficiency.—The efficiency varies widely with different types of lamps and different grades of carbons. The highest efficiency is obtained by the use of the golden yellow light. This with clear globes has an efficiency of .30 to .35 watts per mean lower hemispherical candle power.

Life of Carbons.—The life of carbons varies from 12 to 200 hours and varies also in the same type of lamp for different grades of carbons.

Recommendations Regarding Carbons.—A good grade of carbons that is suitable for the type of lamp in hand is necessary. In connection with some of the lamps only special carbons designed for that particular lamp can be used. The carbons may be either cored or solid but when cored carbons are used with alternating currents both should be cored. For direct currents if a cored carbon is to be used it should be the positive. The resistance of a long thin carbon such as are used is high and it becomes necessary to use either a sliding contact so that the current need not traverse the whole length of carbon or the resistance of the carbon must be reduced. The usual method of reducing the resistance consists in inserting a wire of proper alloy in the carbon.

General Advantages.—The most notable advantages are: High efficiency, variable color of light and with most types long life of carbons.

General Objections.—Lamps cannot be obtained in small units; high intrinsic brilliancy; high first cost; high cost of maintenance.

THE A. B. REGENERATIVE FLAME ARC LAMP

This is an enclosed arc lamp fitted with an inner and an outer globe. The inner globe is connected to two side tubes designed to cause the gas from the arc to circulate and be reheated by the arc.

Systems with Which They May Be Used.—Lamps of this kind are made for use on alternating and direct current either in multiple or in series. A direct, constant current lamp is also made.

Principal Uses.—The main uses of this lamp are for the illumination of large areas where lamps can be placed at some height.

Voltage.—The lamp requires about 70 volts across the arc. It is also made for use singly on 110 to 130 volt circuits and for 2 in series on circuits of from 200 to 250 volts. A series lamp is made for use on constant current circuits and it is also possible to operate these lamps on street railway 550 volt circuits.

Current Used.—The direct current constant potential lamp requires 5.5 amperes and the alternating current lamp 7 amperes.

Rating in Candle Power.—The lamp has an intensity of 1900 mean lower hemispherical candle power and the candle power at the point of maximum illumination is equal to 2600.

Color of Light.—The light is of a yellowish color similar to most flaming arcs.

Natural Distribution of Light.—The distribution of light is good and is nearly all in the lower hemisphere. The point of maximum intensity is about 30 degrees below the horizontal.

Efficiency.—The efficiency is about .30 watts per mean lower hemispherical candle power.

Life of Carbons.—The life of a pair of carbons on direct current is about 70 hours and about 60 with alternating currents.

Recommendations Regarding Carbons.—Special carbons must be used in connection with this lamp.

General Advantages.—The principal advantages of this lamp are its high efficiency and long life of carbons.

General Objections.—The first cost of lamp is high and the cost of maintenance is higher than that of most other arc lamps, excepting only the other flaming arcs.

THE MAGNETITE, LUMINOUS OR METALLIC FLAME ARC LAMP

In this lamp the positive electrode is made of copper and the negative is an iron tube into which a mixture consisting mostly of magnetite, oxide of chromium and oxide of titanium is compressed. In the General Electric lamp the negative electrode is placed at the bottom and in the Westinghouse lamp it is placed at the top.

Systems with Which It May Be Used.—This lamp requires direct currents and can be operated on alternating current circuits only by the use of some form of rectifier. On direct current circuits it may be

operated either on constant potential or on constant current circuits but lamps are not interchangeable.

Principal Uses.—This lamp is used only for street and yard lighting and in some industrial plants where there is sufficient ventilation to carry off the fumes.

Voltage.—The lamp requires about 80 volts at its terminals.

Current Used.—Two sizes are made requiring respectively 4 and 6 amperes. The 4 ampere lamp is the one principally used.

Rating in Candle Power.—The lamp has an intensity ranging from 400 to 600 mean lower hemispherical candle power.

Color of Light.—The light is of white color and well suited for all ordinary purposes.

Natural Distribution of Light.—Most of the light is derived from the flame of the arc. With clear globes the point of maximum intensity is from 10 to 20 degrees below the horizontal.

Efficiency.—The efficiency of the series lamp used with clear globes is about 0.80 to 0.90 watts per mean lower hemispherical candle power.

Life of Electrodes.—The life of the negative electrode is about 4000 hours and that of the positive from 150 to 225 hours.

General Advantages.—The color of the light is satisfactory and the efficiency quite high. The distribution is well suited to street lighting and the illumination of large areas where there is sufficient ventilation. The cost of maintenance is low.

General Objections.—The first cost of the lamp is high. The lamp gives off strong fumes and cannot

Arc Lamp Data

Type of lamp	Current in amperes	Voltage across arc	Color of light	Point of maximum intensity when used with clear glass globes	Watts per mean spherical candle power	Hours of life of pair of carbons
Open arcs						
Direct current series	6.5—7 9.6—10	45	Nearly white	45° below the horizontal	1.20—1.30	12—14
Direct current multiple	6—10	45	Nearly white	45° below the horizontal		12—14
Alternating current series	10—15	40	Blue white	Without reflectors 60° above and 60° below the horizontal	1.7—2	8—12
Alternating current multiple	10—15	28	Blue white			8—12
Enclosed arc						
Direct current series	6—6.6	75—80	Bluish white	45° below the horizontal	1.8—2	80—200
Direct current multiple	3—7	75—80	Bluish white	45° below the horizontal	2.60—3.50	80—200
Direct current multiple		140—160	Blue white to violet			80—150
Alternating current series	6—7	75—80	Bluish white	Without reflectors 60° above and 60° below the horizontal	2.40—2.60	80—150
Alternating current multiple	5—6	75—80	Bluish white		2.80—4	80—150
Intensified arc	3.5—5	80	White		1.8—2	80—100
Flaming arc series	6—12		Depends on the carbons used	With inclined carbons directly under lamp, with vertical carbons	0.25—0.35	12—200
Flaming arc constant potential current	6—12	35—70		20-30° below the horizontal	0.30—0.60	12—200
Regenerative flame arc series	5.5—7	70	Yellow	30° below the horizontal	0.30—0.45	60—70
Regenerative flame arc multiple		70	Yellow		0.40—0.60	60—70
Magnetite series	4—6	80	White	10° 20° below the horizontal	1.30—1.50	150—225
Magnetite multiple	4—6	80	White		1.60—1.80	150—225

be used in small enclosed spaces. It cannot be used on alternating current circuits unless some form of rectifier or converter is used.

INCANDESCENT LAMPS

Systems with Which They May Be Used.—The incandescent lamp can be used in connection with any existing system of lighting. It is merely a question as to how they are to be arranged in series or multiple.

A partial exception to this is the tantalum lamp which is never recommended in connection with alternating currents; also series multiple systems which are not generally sanctioned by safety rules.

Principal Uses.—It is serviceable for any kind of work, but mostly used where an even illumination is desired and where it is possible to place lights close to the plane to be illuminated.

Voltage Required.—Incandescent lamps are being manufactured for voltages ranging from 2 to 250 volts. On circuits of higher voltage lamps may be connected in series and used with any voltage obtainable. The commercial systems in general use require lamps from 200 to 250 volts; 100 to 125 volts; 57 to 65 volts; 27 to 34 volts; and for special purposes they are made in any desired voltage. The lower voltages are used on steam railroads, automobiles and sometimes in small isolated plants. On a large scale lamps are usually of the first two voltages only, either 110-125 or 220-250.

Current Used.—Practically all lamps are now rated in watts and the current required by any single lamp

can be found by dividing the wattage of the lamp by the voltage required.

Incandescent lamps taking singly only a small current can be arranged multiple series with arc lamps and other devices requiring much more current. Safety rules should be consulted before this method of lighting is attempted.

Natural Distribution of Light.—This is mostly in the horizontal plane but varies with different forms of filament. As a rule, for good illumination, reflectors are required.

Color Value.—The color value of the different makes of lamps is in the following order: The tungsten or mazda lamp has a very good color value and is much superior to the others. Next to it comes the tantalum and finally the graphitized or gem and carbon lamps in the order named. None of them are as good as the intensified arc or the Moore light.

Life of Lamps.—Incandescent lamps are fragile and many of them are broken through careless handling. Aside from this the life of these lamps varies inversely with the voltage maintained at terminals of lamps. If they are burned at a low voltage the light given out will be poor but the life of lamp will be greatly prolonged. If used with a higher voltage the light obtained will be vastly increased but the life of lamp will be considerably shortened. A lamp subject to an abnormally high voltage, for instance double its rated voltage, will burn out in a few minutes; often in a few seconds.

From continued use the efficiency decreases constantly and the useful life of the lamp is usually

reckoned as the number of hours it may be used before the candle power falls to 80 percent of its initial efficiency.

Practical Hints.—In order to obtain satisfactory results with incandescent lamps the following points should be observed:

The voltage regulation of the circuit should be good. Lamps should be replaced by new ones when dim or the bulbs are blackened by deposits from the filament.

Lamps and shades should be kept clean, and shades or reflectors should be suited to the purpose.

Lamps placed in the line of vision should be frosted or enclosed in proper globes or shades which reduce the intrinsic brilliancy.

Lamps should be used at the voltage intended, which is ordinarily marked on the bulb or base.

It is the practice of most manufacturers to mark standard lamps with three voltages known as top, middle and bottom voltage. There is a difference of 4 volts between top and bottom.

Ordinarily the lamps should be used at the top voltage; the light is whiter and of a better color value and the efficiency is higher. These advantages in most cases more than offset the slightly reduced life of lamp and consequent increase in cost of lamp renewals.

Where the voltage regulation is poor and liable to produce pressure in excess of that marked on the lamp, lamps should be normally operated at the low voltage, that is, the lamps should be chosen so that the low voltage marked on the lamps is equal to the mean voltage of the source of supply.

For series work lamps should be specially selected to operate at the same current. Lamps taken at random will give very uneven results.

Incandescent lamps will not ordinarily give good illumination on alternating current circuits at a frequency lower than 40 cycles. If it is necessary to operate at lower frequency the lighting should be arranged to use heavy filament lamps as these will not cool so readily and thus the flickering will not be so noticeable. As carbon filaments are thicker than other filaments when of the same candle power they are sometimes preferred for low frequencies.

Lamp Bases.—Practically all lamps used in this country are fitted with the well known Edison base.

An extra large base measuring 1½ inches in diameter is generally used for series lamps in street lighting. Such lamps are also often equipped with automatic cutouts which shunt the current around the lamp in case it burns out.

The large socket mentioned above is also used in connection with large incandescent lights.

The standard Edison base measures 1 1/32 inch in diameter and is the one used on most lamps.

The Edison candelabra base is 7/16 inch in diameter and is largely used for decorative purposes. This base is not much used where a single lamp requires more than 30 watts or a voltage in excess of 125.

The Edison miniature base measures ⅜ inches in diameter and is generally used only for low voltages and small candle power lamps.

The Edison small miniature or midget is very seldom used.

The Edi-Swan base, 5/8 inches in diameter, is of the bayonet type and is sometimes used on automobiles and in other places where there is much jarring.

The smaller miniature lamps are sometimes made without bases, two wires being soldered direct to the lamps.

In a few old installations the T. H. base still remains in use and adapters are often used to fit Edison base lamps to these sockets. These bases come only in standard sizes, no miniature sockets or lamps being obtainable.

Lamp Forms.—Incandescent lamps are obtainable in many shapes varying from the well known pear shape which is the most used, to shapes resembling fruits, flowers, cupids, etc., designed for Christmas trees and decorative effects.

For large size tungsten or mazda lamps the round bulb seems to be preferred.

The meridian lamp has a large spherical bulb which is silvered on the top and reflects most of the light downward. The filament is usually in the form of a horizontal helix. It is seldom used. This must not be confused with the meridian shaped bulbs often used with incandescent lamps.

A long lamp carrying a straight filament with a terminal at each end is much used for show window, show case and similar lighting.

Turn Down Lamps.—This style of lamp is used where a dim light is sufficient most of the time but

where it is also desirable occasionally to use the same lamp for bright illumination. Some of these lamps are fitted with two filaments which are in series when the light is to burn dim. Other lamps have a resistance which is cut into the circuit to dim the light.

Frosting.—Lamps are frosted to reduce the intrinsic brilliancy. With frosted lamps the whole surface of the globe becomes luminous instead of merely the filament and the intensity of the light is thus correspondingly reduced.

Incandescent lamps may be frosted by the use of acid or sand blast. These methods are weatherproof and permanent but leave the lamps rough and liable to gather dirt which is difficult to remove.

The commonest method of frosting consists in dipping the lamps in certain solutions. This leaves a smooth surface and the lamps are more easily kept clean but this method is not permanent and not suitable for use in exposed locations.

Frosting reduces the candle power of lamps from 3 to 10 per cent.

Frosting the whole body of the lamp reduces the life of carbon filament lamps from 30 to 50 per cent.

Bowl frosting does not materially reduce the life of lamps.

Coloring.—Lamps are ordinarily colored to strong solid colors for decorative effects, but often in theatres and similar places a few light amber colored lamps are mixed in with the white to give more or less "warmth" to the light.

Lamps made up of colored glass are obtainable and

well suited for out-door use but are quite expensive. Dipped lamps are therefore mostly used.

Coloring reduces the candle power considerably and also the life. The relative absorption is shown in the following order, colors of the highest light efficiency being given first.

The best colors for lamps are opal, yellow and amber.

Blue, green and purple are undesirable, as these colors absorb most of the light.

Blue and red are the most used colors.

Types of Incandescent Lamps.—Incandescent lamps may be divided into four classes, the classification being based upon the material of which the filament consists. In the order of present day importance these are: The tungsten or mazda; tantalum (for direct current only); the graphitized filament lamp well known to the trade as the "gem" or "metallized" and finally the old, well known carbon filament lamp.

THE TUNGSTEN LAMP

This lamp is also known as the mazda. The metal, tungsten of which the filament consists is quite rare but can be burned at a very high temperature without that rapid deterioration which accompanies the carbon filament lamp when heated to a very high temperature. For this reason the lamp is very efficient.

The first filaments were made by forming the powdered tungsten into a paste and then squirting the paste into the form of a filament which was

afterwards raised to a high temperature. The filaments produced this way at first were very fragile but improved methods of working have overcome this defect to a large extent.

The filaments are now being made in the form of a wire by most manufacturers.

Sizes Obtainable. (*See Table.*)—As the specific resistance of the metal is low, the filament must either be made very long or very fine to limit the current and hence tungsten lamps are not made in small sizes for standard voltages of 110 or 220.

Small candle power lamps are, however, made to operate in series or in connection with low voltage transformers.

Owing to its good efficiency the tungsten lamp is crowding the arc lamp out of service in many places and for this purpose is made in special sizes running as high as 500 watts per lamp which is equal to about 400 candle power.

Efficiency.—This is the most efficient of all the incandescent lamps requiring about 1.25 watts per horizontal candle power.

Recommendations.—The tungsten lamp is to be recommended in all places where lamps may be hung vertically; where there is not an excessive amount of jarring; where there is ordinary care in handling and where the lamps are burning a great part of the time.

The operating expenses of these lamps are low but the initial cost is high and if not used much, the chances are that the breakage will exceed the saving in energy.

Practical Hints.—Where possible tungsten lamps

Table Showing Rating of Standard Mazda or Tungsten Multiple Incandescent Lamps.

	Nominal watts	Volt'ge rating	Actual watts	Watts per c. p.	Mean horizontal c. p.	Total lumens	Lumens per watt	Hours of life
100 to 125 volts	25	top	25.0	1.31	19.1	187	7.48	1000
		middle	24.2	1.37	17.7	173	7.16	1300
		bottom	23.4	1.43	16.4	160	6.85	1700
	40	top	40.0	1.23	32.5	319	7.97	1000
		middle	38.9	1.28	30.4	298	7.67	1300
		bottom	37.8	1.33	28.5	277	7.37	1700
	60	top	60.0	1.18	50.8	498	8.30	1000
		middle	58.2	1.23	47.3	464	7.97	1300
		bottom	56.5	1.28	44.2	433	7.67	1700
	100	top	100.0	1.18	84.7	830	8.30	1000
		middle	97.0	1.23	78.9	773	7.97	1300
		bottom	94.2	1.28	73.6	722	7.67	1700
	150	top	150.0	1.18	127.0	1245	8.30	1000
		middle	145.5	1.23	118.3	1160	7.97	1300
		bottom	141.2	1.28	110.4	1083	7.67	1700
	250	top	250.0	1.13	222.0	2168	8.67	1000
		middle	242.0	1.18	204.2	2009	8.30	1300
		bottom	235.0	1.23	191.0	1873	7.97	1700
	400	top	400.0	1.13	354.0	3470	8.67	1000
		middle	387.0	1.18	328.0	3215	8.30	1300
		bottom	376.0	1.23	306.0	3000	7.97	1700
	500	top	500.0	1.13	442.0	4335	8.67	1000
		middle	484.0	1.18	410.0	4020	8.30	1300
		bottom	470.0	1.23	382.0	3745	7.97	1700
200 - 250 volts	45	single	45.0	1.48	30.4	302	6.71	800
	60	single	60.0	1.48	40.5	402	6.71	800
	100	single	100.0	1.48	67.6	671	6.71	800
	150	single	150.0	1.48	101.4	1006	6.71	800
	500	single	500.0	1.23	407.0	4035	8.07	800

15 and 20 watt lamps are now obtainable for voltages of 100 to 125.

should be placed in a vertical position but they may (especially the wire drawn filament) often be used in a horizontal position with good results.

Avoid cleaning lamps when cold.

In placing lamps where there is much jarring use shock absorbers. Where practical, lay out illumination for units not smaller than 60 watts.

Do not use tungsten lamps for coloring.

Do not use for temporary work.

Arrange lamps as much as possible to be controlled by switches.

Broken filaments can often be united again by shaking the lamp until the ends come together. The current then welds them together. The hot resistance of these lamps is from 10 to 12 times as high as that of the cold lamps. There is therefore an excessive current for an instant when the lamps are turned on. This is the cause of the "overshooting" of tungsten lamps.

THE TANTALUM LAMP

In this lamp the filament is a fine wire of tantalum. Tantalum is a hard metal having a tensile strength equal to that of mild steel and a very high melting point. The hot resistance of the filament is from 5 to 5.5 times greater than when cold and the lamp is less sensitive to fluctuations in voltage than the carbon filament lamp or the graphitized lamp.

When new, the filament is smooth, but after burning for some time it becomes pitted and assumes a crystalline appearance. These pittings develop much more rapidly on alternating than on direct current and with a frequency of 60 cycles the life of the lamp is only about half of what it is on direct current. With higher frequencies the life is shortened still more.

On direct current circuits the life is about the same as that of the average carbon lamp.

Sizes Obtainable. (*See Table.*)

RATING OF STANDARD MULTIPLE TANTALUM LAMPS.

	Nominal watts	Volt'ge rating	Actual watts	Watts per c. p.	Mean horizontal c. p.	Total lumens	Lumens per watt	Hours of life on d. c.
100 to 125 volts	25	top	25.0	1.97	12.7	126	5.04	1000
		middle	24.2	2.05	11.8	117	4.83	1300
		bottom	23.5	2.14	11.0	109	4.64	1700
	40	top	40.0	1.79	22.3	221	5.54	800
		middle	38.8	1.87	20.7	206	5.31	1100
		bottom	37.6	1.95	19.3	191	5.09	1500
	50	top	50.0	1.79	27.9	277	5.54	800
		middle	48.5	1.87	25.9	257	5.31	1100
		bottom	47.0	1.95	24.1	239	5.09	1500
	80	top	80.0	1.79	44.6	443	5.54	600
		middle	77.6	1.87	41.5	412	5.31	800
		bottom	77.2	1.95	38.6	383	5.09	1050
200 250 volts	50	single	50	1.97	25.4	249	4.98	800
	80	single	80	1.97	40.6	398	4.98	800

Efficiency.—The efficiency at top voltage is from 1.8 to 2 watts per candle power.

Recommendations.—The lamp is used on street car and similar service. It is also well suited for all ordinary work where the tungsten cannot be used. The color value ranks next to that of the tungsten. It is not recommended for alternating current circuits.

Practical Hints. Like the tungsten, if the filament becomes broken it can often be united again by shaking the lamp a little until the ends of filament come together. If in this operation much of the filament is cut out the candle power and current consumption will be increased.

GRAPHITIZED FILAMENT LAMP

In the graphitized or gem lamp the carbon used as a filament is heated to a very high temperature in

an electric furnace. This reduces the resistance and produces a tough outer coating which is practically all graphite. The center is not affected much. This lamp is also spoken of as the metallized filament lamp. It has a positive temperature coefficient and is consequently less sensitive to fluctuations in voltage than the carbon lamp.

The useful life of the lamp is about the same as that of the carbon lamp and the color value is a little better.

Sizes Obtainable.—On account of the low resistance of the filament it has not been found practical to manufacture these lamps for the smaller sizes or for voltages higher than 125. See table.

RATING OF STANDARD GEM INCANDESCENT LAMPS
100 TO 125 VOLTS

Nominal watts	Voltage rating	Actual watts	Watts per c. p.	Mean horizontal c. p.	Total lumens	Lumen per watt	Hours of life
40	top	40.0	2.50	16.0	164.2	4.11	500
	middle	38.8	2.65	14.6	149.5	3.86	700
	bottom	37.8	2.83	13.3	134.5	3.56	1000
50	top	50.0	2.50	20.	205.2	4.11	500
	middle	48.5	2.65	18.3	187.0	3.86	700
	bottom	47.2	2.83	16.7	168.1	3.56	1000
80	top	80.0	2.50	32.0	328.4	4.11	500
	middle	77.6	2.65	29.3	299.2	3.86	700
	bottom	75.6	2.83	26.7	269.0	3.56	1000
100	top	100	2.50	40.0	410.4	4.11	500
	middle	97	2.65	36.6	374.0	3.86	700
	bottom	94.5	2.83	33.4	336.2	3.56	1000

Gem lamps are also made in 125, 187½ and 250 watt sizes. The 200 and 250 watt sizes are not used to any extent.

Efficiency.—The efficiency is about 2.5 watts per candle power.

Recommendations.—This lamp is sold at low price and is generally preferable to the carbon lamp if obtainable in the sizes wanted.

CARBON FILAMENT LAMPS

The carbon filament has a negative temperature coefficient of resistance; the resistance of a lamp when cold being about two times as high as when burning at normal voltage. An increase in voltage will cause a further reduction in resistance and an increase in current so that the lamp is the most sensitive of all in regard to voltage regulation. Slight changes in voltage also affect the useful life of the lamp as well as the color of the light, the efficiency and the quantity.

The color of the light is yellowish white and is not as well adapted for judging and comparing colors as the other incandescent lamps. It is, however, superior to the ordinary gas light. A yellowish light is preferred by some on account of the warmth of color and sometimes even a slight amber tint is given to lamps in places where color values are not essential.

Sizes Obtainable.—The carbon filament lamps are the only lamps at present obtainable commercially in small units for standard voltages of 110 or 220. They are not made in the large sizes for which tungsten lamps are obtainable. On account of the low efficiency of the lamps there could never be any demand for large sizes because arc or Nernst lamps would be preferable.

Ratings of Standard Carbon Filament Incandescent Lamps

	Nominal watts	Volt'ge rating	Actual watts	Watts per c. p.	Mean horizontal c. p.	Total lumens	Lumens per watt	Hours of life
100 to 125 volts	10	single	10	5.00	2.	21.3	2.13	2000
	20	single	20	4.15	4.8	50.3	2.52	2000
	25	top	25.	3.10	8.1	83.6	3.34	500
		middle	24.1	3.34	7.3	75.4	3.14	725
		bottom	23.2	3.52	6.6	68.3	2.94	1050
	30	top	30.	3.23	9.3	96.4	3.21	1050
		middle	28.9	3.46	8.4	87.0	3.00	1500
		bottom	27.8	3.69	7.5	77.7	2.81	2100
	50	top	50.	2.97	16.8	174.0	3.49	700
		middle	48.2	3.18	15.2	158.0	3.26	1000
		bottom	46.4	3.39	13.7	142.0	3.06	1500
	60	top	60.	2.97	20.	208.0	3.49	700
		middle	57.9	3.18	18.3	190.0	3.26	1000
		bottom	55.7	3.39	16.4	170.0	3.06	1500
	100	top	100	2.97	33.6	349.0	3.49	600
		middle	96.4	3.18	30.5	316.0	3.26	850
		bottom	92.9	3.39	27.4	284.0	3.06	1350
	120	top	120	2.97	40.4	419.0	3.49	600
		middle	115.8	3.18	36.6	379.0	3.26	850
		bottom	111.4	3.39	32.8	340.0	3.06	1350
200 - 250 volts	35	single	35.	4.40	8.0	84.0	2.40	100
	60	single	60	3.69	16.3	171.0	2.84	750
	120	single	120	3.69	32.5	340.0	2.84	750

Efficiency.—The best carbon filament lamps in the sizes ranging from 25 to 100 watts used on 110 volt circuits have an efficiency of from 3 to 3.2 watts per mean horizontal candle power.

The efficiency of the smaller sizes used at 110 volts ranges from 4 to 5 watts per mean horizontal candle power.

200 to 260 volt lamps have an efficiency ranging from 3.7 to 4.4 watts per mean horizontal candle power.

Recommendations.—While the carbon filament lamp is in most respects the poorest of all the in-

candescent lamps, still on account of its ruggedness and cheapness it can be recommended for all places in which the breakage is great or where lamps are actually used only for very short periods of time. Such places are closets, attics, basements, halls, etc., where only small candle power lamps are used or for coloring, for decorative purposes, for temporary lighting and portable purposes.

Practical Hints.—Never use carbon filament lamps on circuits on which the voltage is apt to rise higher than top voltage of lamp.

THE MOORE TUBE

Systems with Which It May Be Used.—The Moore tube is essentially a large Geissler tube. It operates on alternating current only and requires that special transformers be provided for each tube.

Principal Uses.—This light is principally of value in color matching. For this purpose it is unexcelled and very nearly equal to daylight. The tubes may be installed along ceilings in any manner desirable and may be of varying lengths. They are also obtainable in small units consisting of a small transformer and necessary quota of tubes mounted in a portable box for use in special locations for illuminations of works of art, etc.

Voltage.—The voltage required varies with the length of the tube and ranges from 2000 to 13,500. The length of tube varies from 25 to 225 feet.

Color of Light.—The color of light can be varied at will and depends upon the nature of the gas through which the current discharge takes place. With carbon dioxide gas the color of the light is practically the same as daylight and is admirably adapted for color matching. When the tubes are kept filled with air the color of light is orange or pink; with nitrogen gas it is yellow.

Natural Distribution of Light.—The tube has the appearance of a long stream of light and the intrinsic brilliancy is low. This makes the distribution very good and even. The illumination due to such a distribution varies directly as the distance of the source from the plane illuminated instead of as the square of the distance with other illuminants.

Efficiency.—No exact information is obtainable but it is believed to be somewhat between 1.5 to 2.5 watts per mean spherical candle power. The highest efficiency is found in connection with the long tubes. The color giving the highest efficiency is yellow.

Length of Life.—Aside from accidental breakage the life of the tubes is practically unlimited. The cost of maintenance is very low.

General Advantages.—The advantages are: a soft mellow light; absence of shadows; adaptability to low ceilings; automatic operation; control over color of light; novelty, which adds greatly to its advertising value.

General Objections.—Necessity of special skill in erecting; high voltage and numerous special transformers.

Practical Hints.—High potential coils and regulating apparatus should be installed in steel cabinets and well ventilated. The terminals of the tube should be in this cabinet.

NEON-VAPOR LAMPS

This lamp is similar to the Moore tube with exception that the tube is filled with neon-vapor.

The color of the light is golden and the efficiency is high.

Neon-vapor tubes are difficult to make and this lamp is still in the experimental stage.

THE MERCURY VAPOR LAMP (GLASS TUBE)

This lamp has the form of a long glass tube which contains a small quantity of mercury and gives off a greenish light. The lamp is normally tilted at an angle so that the mercury is always at one end of the tube.

There are different methods of starting the lamp. Most lamps are started by momentarily tilting the lamp after current has been turned on so that the mercury will run from one side of the tube to the other. The current follows the mercury and when it breaks the circuit the arc is established.

Some lamps are provided with magnets which do the tilting automatically when current is turned on.

Still other forms of lamps are started by establishing a voltage sufficiently high to break down the resistance of the tube and start the current. The high

voltage is used only for a moment and the low pressure current then takes its place. The high voltage necessary for this method may be obtained by the use of an induction coil.

In most lamps that are operated without tilting a shifter is used. This is an evacuated glass tube partially filled with mercury. When the circuit is closed an electric magnet shifts this tube and breaks the current inducing a high voltage which starts the arc.

Systems with Which They May Be Used.—These lamps may be used with alternating or direct current systems. When used on alternating current systems this lamp utilizes the principle of the mercury arc rectifier and becomes a self rectifying tube with all necessary appliances in the lamp auxiliary.

Principal Uses.—The lamps are limited to use in localities where color values are of no importance. Their place of greatest utility is in photographic work, and here they are considered superior to all other means of artificial illumination.

They are also much used in machine shops and in drafting rooms.

Voltage.—Tubes are made of various lengths and for voltages ranging from 50 to 240 per lamp. (See table.)

Current Used.—The current ranges from 2 to 3.5 amperes per set. (See table.)

Rating in Candle Power.—The candle power per lamp ranges from 300 to 900. (See table.)

TYPES OF COOPER-HEWITT MERCURY VAPOR LAMPS

Type of lamp	Current	Length of tube in inches	Current in amperes	Volt'ge per lamp	Watts per lamp	Watts per mean lower hemispherical candle power	Mean lower hemispherical candle power of lamp with reflector	REMARKS
H	d. c	20¾	3.5	50 to 60	175 to 210	0.64	300	Used 2 in series on 100-120 volts or 4 in series on 200 to 240 volts.
K	d. c	45	3.5	100 to 120	350 to 420	0.55	700	Used in multiple on 100-120 volts or 2 in series on 200 to 240 volts.
P	d. c	50	3.5	100 to 120	350 to 450	0.48	800	Used in multiple on 100-120 volts or 2 in series on 200 to 240 volts.
U	d. c	78	2.	200 to 240	400 to 480	0.48	900	Used in multiple on 200-240 volts.
F	a. c 60cycles	50		100 to 240	350 to 430	0.51	670 to 850	Used in multiple on 100, 110, 200, 220 or 240 volts.

Color of Light.—The color of the light is a greenish blue. It gives a ghastly effect and is said to have a depressing effect on many. It appears to be well liked by some and very distasteful to others. The light is said to be deceptive and unreliable for such work as pattern making, etc. Special forms of this lamp in which the color has been improved are now to be had. One method of improving the color consists in adding a carbon filament lamp to the tube. Another method consists of adding a fluorescent screen which greatly improves the color.

Natural Distribution of Light.—The light is of low intrinsic brilliancy and well diffused thus avoiding objectionable shadows, and the distribution must be considered good.

Efficiency.—The distribution of light with reflectors is nearly all in the lower hemisphere and the efficiency here is as low as .48 to .64 watts per mean lower hemispherical candle power.

Life of Tubes.—An average length of life of 5,000 hours is now claimed for the tubes.

General Advantages.—High efficiency; low cost of wiring; ease of operation. Absence of strong shadows.

General Objections.—Color of light; flickering of light with alternating currents; low power factor. Deceptive appearance of surfaces illuminated.

Practical Hints.—Limit circuits to one lamp, or series of lamps. Use double pole switches; avoid plug cutouts for 220-volt circuits. Avoid armored cables and twisted cord or wires, these for some unexplained reason are said to shorten life of tubes. With direct current lamps, be sure that the polarity is right before starting. When mercury vapor lamps are used in places where inflammable gases exist, the spark of the automatic cutout hammer which releases the solenoid is dangerous and special lamps must be used in such places.

THE QUARTZ TUBE MERCURY VAPOR LAMP

This lamp is provided with a quartz tube which will stand a much higher temperature and pressure than glass. The tube is also of much smaller dimensions than the glass tube of the Cooper-Hewitt lamp

being only about 3.2 inches in length for the 110-volt lamp.

The quartz tube is covered by a glass globe and the outward appearance is about that of an ordinary arc lamp. The effect of the light from the quartz tube is injurious to the eyes but this may be overcome by the use of special glass in the manufacture of the outer globe which absorbs the injurious rays.

Systems with Which It May Be Used.—This lamp may be used in multiple in connection with all standard voltages.

Principal Uses.—The lamp is used in Europe for the lighting of factories, mills and other places where large units are suitable and where color values are not essential.

Voltage.—Lamps are made for use in multiple on circuits of 110-130 to 200-250 volts.

Current Used.—The 110-volt lamp requires 4 amperes and the 220-volt lamp from 2½ to 3½ amperes.

Rating in Candle Power.—The mean lower hemispherical candle power ranges form 12 to 3,000.

Color of Light.—On account of the high temperature of the tube and the short arc, the color of the light is much better than that of the glass tube vapor lamps. It is considered satisfactory for lighting in most places where it is not necessary to match colors.

Natural Distribution of Light.—The point of maximum intensity is directly below the lamp and nearly all the light is distributed in the lower hemisphere.

Efficiency.—The efficiency ranges from .20 to .25 watts per mean lower hemispherical candle power,

and is probably better than that of any other electric lamp.

Life of Tube.—An average life of 2,000 to 3,000 hours is claimed for the tube.

General Advantages.—The lamps can be used in multiple on standard voltages. The efficiency is probably higher than that of any other lamp. Mechanically the lamp is very simple and there is very little to get out of order about it.

About the only attention necessary to give to it consists in cleaning the globes occasionally and replacing burned out tubes.

General Objections.—The lamps are not obtainable in small sizes and on account of the large candle power and peculiar distribution of light must be hung high.

The cost of tubes is high.

It is not well adapted for color matching.

THE NERNST LAMP

In the Nernst lamp the radiating part is known as the glower and from 1 to 6 are used in each lamp. The glower is a composition of oxides of rare earths and is an insulator when cold. Before the glower will admit of current flow enough to cause incandescence it must be heated. This heating is accompished by means of resistance mounted near the glowers. Each lamp also contains what is known as the "ballast" which serves to steady the current.

Systems With Which It May be Used.—The Nernst lamp may be used with alternating or direct cur-

rents but operates best with alternating current at a frequency of about 60 cycles or more. They are not well suited for low frequencies and work better on direct current than at 25 cycles.

Principal Uses.—They are used in office and shop lighting and by some well liked for color matching. They are suitable for any kind of lighting except where quick changes are necessary as in theatres.

Should be installed only where intelligent care is assured.

A special form of lamp is made for street lighting in which the glowers are mounted vertically.

Voltage.—The Nernst lamps are made for either 110 or 220 volts. The sizes used for 110 volts are 66-110 and 132 watts. These sizes are made in single glower lamps and for use on fixtures or drop cords.

All 220-volt alternating current lamps can be used for 110 volts by installing special converter coils made for that purpose. The 220-volt lamps are made in the following sizes: 88, 110, 132, 176 and 220 watts. The 176 and 220 watt glowers are made only for single glower lamps. The other sizes are used singly or on multiple glower lamps and on Nernst chandeliers.

Current Used.—The 110-volt glowers require 0.6, 1.0 and 1.2 amperes per glower. The 220-volt glowers require respectively .4, .5, .6, .8 and 1 ampere per glower.

Rating in Candle Power.—The intensity of the light ranges from 48 to 600 mean lower hemispherical candle power according to sizes.

Color of Light.—The light is of a good color and

well liked by many for color matching and display of colored fabrics. When used with blue alabaster enclosing globes the color is about the same as that of the tungsten lamp.

Natural Distribution of Light.—The light is always thrown downward and the lamp requires no reflectors. The distribution is very good.

Efficiency.—The efficiency is highest with the larger sizes and equal to about 1.2 to 1.5 watts per mean lower hemispherical candle power, or 2 to 2.5 watts per spherical candle power.

Life of Glowers.—The intensity of the light drops off rapidly with age. The average life of glower is about 800 hours and the candle power drops off fully 20 per cent.

General Advantages.—The light is steady and when opalescent or ground glass globes are used it is also pleasant. The power factor is much better than with arc lamps.

Objections.—Frequently one or more of the glowers burn out without the fact being noticed, thus giving an unsatisfactory light. A steady voltage is required as otherwise the light is quite variable. The light does not attain its full brilliancy until about 15 or 30 seconds after it has been turned on. They require nearly as much attention as arc lamps. With clear globes very strong shadows are thrown. Cannot be used in theaters where quick changes are necessary.

Practical Hints.—Limit each branch circuit to 660 watts; provide double pole switches; hang lamps high.

Table below is prepared from data taken from the publications of the Westinghouse Electric and Manufacturing Co., and shows at the right the number of square feet Nernst lamps of the wattage given at top of table will properly illuminate under the conditions given in the corresponding part of the table at the left. The figures given are for average conditions.

TABLE SHOWING NUMBER OF SQUARE FEET NERNST LAMPS WILL ILLUMINATE

NATURE OF SPACE TO BE ILLUMINATED	WATTAGE OF LAMPS					
	66	88	110	132	176	220
Machine shops — high roofs; no belts	88	117	146	176	234	293
Machine shops — low ceiling, belts and other obstructios	66	88	110	132	176	220
Hardware and shoe stores	88	117	146	176	234	293
Department stores handling light material and bric-a-brac	66	88	110	132	176	220
Department stores handling colored material	52	70	88	105	132	165
Mill lighting, plain white goods	60	80	100	120	160	200
Mill lighting, colored goods and high looms	50	67	85	101	135	169
General office work	44	59	73	88	118	147
Drafting rooms	37	41	62	75	100	125
Reception hall	82	110	137	165	220	275
Dining room	110	147	183	220	293	366
Church and lecture hall	66	88	110	132	176	220

The following elevations are recommended for Nernst lamps:

Type of lamp	Height above floor
Two and three glower	11½ feet
Four glower	13 feet
Six glower	14 feet
55 watt	9 feet
88 watt	10 feet

CHAPTER VIII

SHADES AND REFLECTORS

Shades, reflectors and enclosing globes if properly selected and applied can be used to reduce the intrinsic brilliancy and reflect the light where needed. While the total illumination is by their use often considerably reduced, the illumination may at the same time be much better. The increase of illumination on the working plane may easily be from 50 to 100 per cent.

Light to be satisfactory should not cast too strong shadows except in a few special cases such as foundries for instance, where all materials soon assume the same color. There should, however, be mild shadows as these will assist in making objects distinguishable. The light from a bare incandescent lamp casts streaks on the illuminated surface and this streakiness is much increased if highly polished reflecting material is used.

The absorption of light by glass varies from about 5 per cent for clear glass to 95 per cent or more for some of the natural colored glass. In considering these losses in connection with shades and reflectors it must be borne in mind that in some forms of reflectors only a small part of the light strikes the

glass while in other forms the light is reflected several times. Where highly absorptive glass is used as for decorative purposes for instance, the shades should be given such a form that much of the light can escape without being reflected while, where totally enclosing shades are required, only glass of low absorptive power should be used. Trade names are often misleading and it is difficult to give even approximate losses in connection with shades and reflectors.

The loss by absorption of the various kinds of glass is about as given in the following table:

Clear glass	8 to 10 per cent
Prismatic glass	10 to 12 per cent
Light sand blasted glass	10 to 20 per cent
Acid etched glass	10 to 20 per cent
Alabaster glass	10 to 25 per cent
Canary colored glass	15 to 20 per cent
Ribbed glass	15 to 30 per cent
Ground and etched glass	15 to 30 per cent
Amber glass	20 to 25 per cent
Opalescent glass	20 to 40 per cent
Cut and pressed glass	20 to 40 per cent
Opal glass	25 to 60 per cent
Bead glass	30 to 60 per cent
Green glass	80 to 90 per cent
Ruby glass	85 to 90 per cent
Blue glass	90 to 95 per cent

Art glass is usually a mixture of the above colors and the absorption will be an average of the colors used.

Shades may be divided into three classes:

Decorative shades intended primarily for decorative effect; diffusing shades intended simply to diffuse the light or reduce its intrinsic brilliancy.

Reflecting shades the purpose of which is to throw all of the light in a certain direction.

Most shades, however, have both diffusing and reflecting qualities and many of them also are arranged to be more or less decorative. Decorative shades as a rule improve the diffusion and also alter the distribution of the light. With many of these the loss is excessive, being often as high as 95 per cent as with some kinds of art glass which is merely absorptive and has no reflecting value. Often the illumination necessary for comfort is wasted entirely to produce socalled artistic effects.

Cut and pressed glass shades, especially when of very elaborate design, are generally very tiresome to the eye and often are worse than useless.

In placing decorative shades with incandescent lamps care should be taken that not too much interference with the illumination is brought about. If this point is well guarded and sufficient extra illumination provided to make up for the unavoidable losses very pleasing decorative effects can be obtained.

The custom of placing lamps on fixtures at an angle of about 45 degrees, as is so often done for the sake of appearance, is entirely uncalled for. The light is thrown where least needed and it is almost impossible to either shade or reflect it properly. The only place where this method would seem to be called for is in connection with large fixtures hung very

high from which a general illumination is expected.

If shades do not obscure the bottom of lamps these, unless quite high above the plane to be illuminated, should be frosted.

Prismatic glass is probably the most efficient material for shades or reflectors, but should not be used where lamps are continually in the field of vision as it does not reduce the intrinsic brilliancy sufficient. In such places it is preferable to use glass of higher absorptive power to reduce the intrinsic brilliancy.

Enclosing globes are often used for decorative effect, but good diffusion and distribution can also be obtained from them if they are properly designed. Their use, however, slightly reduces the life of the lamp probably from 3 to 5%. A piece of asbestos or other reflecting material that will not be affected by the heat will increase the efficiency and keep out dirt. This is often used with bowls for ceiling lamps with good results. As enclosing globes entirely cover the lamp they are usually preferred where lamps are hung low. With sand blasted, acid etched or other rough glasses a considerable reduction in the losses due to dirt can often be effected by providing the rough side for that part of the glass least exposed to dirt. A satin finish on the inside of prismatic reflectors softens the light but must be kept clean or the loss in illumination will be large.

A protective covering is necessary for all arc and Nernst lamps and is generally used also to reduce the intrinsic brilliancy and improve the distribution of the light, also for the purpose of improving the color of the light.

Spherical balls can be used in many paces to combine a pleasing appearance with good diffusing and reflecting qualities. With the well known Holophane balls this can be accomplished with a small loss by absorption.

Reflectors should be used only in connection with such lamps as they are designed for and also in the proper holders. Any change in the relative position of lamp and reflector will affect the distribution of the light. This applies with much more force to scientifically designed reflectors than to the ordinary haphazard kind.

Opaque reflectors cast objectionable shadows upon the ceiling and in most cases reflectors that allow some of the light to reach the ceiling are preferred.

Reflectors that do not shade the source of light should be used only in connection with frosted lamps or with lamps hung out of the range of vision.

REFLECTING MATERIAL

Clear Glass.—This is seldom used for shades and has very low reflecting power and no diffusing qualities. Its use is practically limited to protective covering in dusty, wet, or gaseous places.

Ground and Etched Glass.—There is not much difference between the two and they may be considered as one. They are generally used where some decorative effects are desired but give a fair degree of diffusion with comparatively little absorption. They have some reflecting power but as a rule do not change the distribution of the light much. If left smooth on one side, however, the reflective powers

are increased and cause a change in the light distribution.

Cut and Pressed Glass.—This glass, whether genuine cut or simply pressed in imitation does not materially change the distribution and the diffusion is generally poor, while the loss by absorption is quite large. Cut or pressed glass looks best by reflected light and when used for shades generally gives a dazzling effect which is tiresome to the eye. As a rule any attempt to produce decorative effects with such glass will give streaked effects. This glass is not desirable and its use is decreasing rapidly.

Bead Glass.—This gives a fair diffusion but the loss by absorption is high. There is much refraction and reflection both of which vary with the degree of closeness of the beads. If the beads are not placed close together the lamp filament will be visible through them, which is a condition that should generally be avoided. Bead glass is difficult to keep clean and unless much attention is paid to cleaning the loss by absorption will be very large. It is used principally where decorative effect is desired and where one is willing to sacrifice much of the light to this end.

The change in the distribution of the light varies with the design and may be quite large.

White or Opal Glass.—This gives good diffusion and the distribution is materially changed by refraction and reflection. This is caused mostly by the particles of opal that are always embedded in the glass. Very dense opal gives nearly perfect diffusion and the enclosing globe or reflector becomes a sec-

ondary source of light. If the opal is dense enough for this, however, the loss by absorption is liable to be very high. If the opal is less dense the diffusion will not be so good and many opal balls and shades allow a red outline of the lamp filament to be seen which is not at all pleasing. It is, however, possible to obtain glass that will give a fair degree of diffusion with a medium loss by absorption. Special care should be taken in the selection of opal shades and glass ware.

Colored or Tinted Glass.—This is used mainly for decorative purposes. Exceptions to this are blue alabaster and opal glass with a strong tinge of yellow. These give fair diffusion with fairly low absorption and can often be used with good effect where it is desired to modify the color of the light or to change the distribution. With most other colors the reflecting power is small but the diffusion may be good varying with the density of the color. The absorption is usually very large.

Art Glass.—Art shades are generally made up of small pieces of colored glass leaded together. The diffusion of such shades is good but they have practically no reflecting power and the absorption loss is exceedingly high.

Sand Blasted and Acid Etched Glass.—This gives good diffusion and the distribution is changed to some extent by refraction and reflection. The loss by absorption is low for light sand blasting and acid etching but may be high for heavy sand blasting. This kind of glass acquires dirt very readily and is difficult to keep clean.

Prismatic Glass.—This is probably the most efficient material in use for shades and reflectors. It consists of glass having prisms on one or both surfaces to refract or reflect the light. The design of the prisms must be made on a scientific basis and must take into account the position and shape of the lamp within the shade or reflector. For the best results a certain lamp must be used only in a certain reflector. With careful design it is possible to obtain almost any kind of distribution of light. It is essentially diffusing and reflecting but nevertheless in appearance it is often more pleasing than other material used mainly for decorative purposes.

For good results prismatic glass should be kept clean although the loss from dirt is not as great as with many other kinds of glass.

Cloth and Paper are sometimes used for reflecting material. They are hard to keep clean and from a safety standpoint if brought close to lamp are objectionable.

Asbestos is a good reflecting material and has been used to some extent, but is difficult to keep clean.

White Painted Metal is sometimes used for reflectors. It is liable to chip off and turn yellow. It has poor reflecting qualities.

Enameled Porcelain is sometimes used for reflectors. Moisture and dirt have less effect on it than on most other reflecting material, and it is easily kept clean. The reflection is largely irregular and the loss by absorption quite high.

Matted or Depolished Aluminum is a good reflector and is largely used as a coating for other metals. It is not strong enough to stand hard usage.

Tin is objectionable on account of the streaks of light produced by it when used as a reflector. It should be used only where the evenness of the light is of no importance.

Zinc has about the same properties as tin.

Polished Steel is a good reflector, but gives the streaked effect so common to all polished metals. Depolished and enameled steels have a lower efficiency but give a better distribution of light. As there are now on the market several good types of steel reflectors, there is no excuse for using bare incandescent lamps in factories. In places where there is much dust or moisture, or where there is liable to be chemical action, enameled steel is the best reflecting material.

Plain Mirror Strip reflectors have a good efficiency when new, but are apt to depreciate rapidly, especially when not of the best quality or when subject to much heat.

Corrugated mirror strips have a lower efficiency but are practically free from the streaks of light produced by plain mirror reflectors.

Silvered Glass has a high efficiency of reflection and nearly any distribution can be obtained from it. Ribbed or corrugated glass should be used in order to avoid the streaked effect.

Light Transforming Reflectors.—The principle on which these reflectors are constructed is that of changing the wave length of the light rays and thus obtain a different color. Such reflectors have been made of a white enamel covered with fluorescent salt. A part of the light striking the reflector is absorbed

which causes the salt to fluoresce and give out rays of a different wave length.

Some experimental work along this line has been done with a view to improving the color of the mercury vapor lamp.

Following are given a number of distribution curves of special reflectors designed for various purposes. Only a few of marked characteristics are given to show that almost any desirable kind of distribution is obtainable and also to show the need of

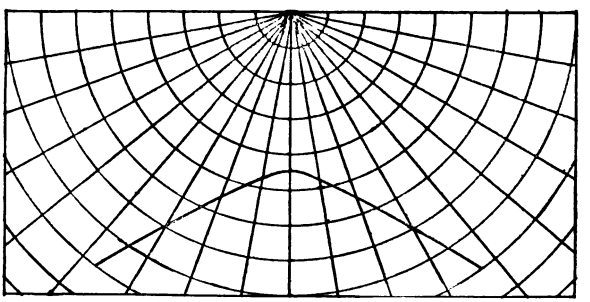

FIGURE 25

care in the selection. Where really good illumination effects are desired the use of reflectors is absolutely essential and from the various figures it can be seen that even very defectively placed lamps can, by the use of proper reflectors, be made to yield fairly good illumination.

In considering these curves it must be borne in mind that the length of the radial lines from the center is proportional to the candle power; that the area enclosed by a curve has nothing to do with the total

illumination and that the light (neglecting reflection from walls and ceilings) decreases as the square of the distance increases. Reflectors can therefore give an even illumination only over a very limited area,

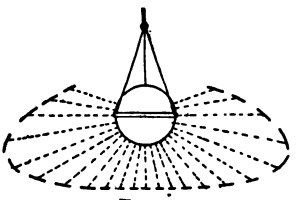

Fig. 26

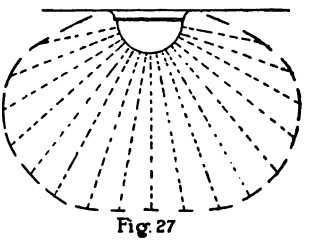

Fig. 27

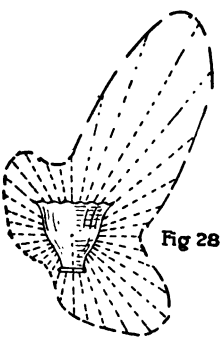

Fig. 28

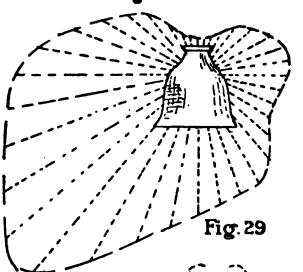

Fig. 29

Fig. 30

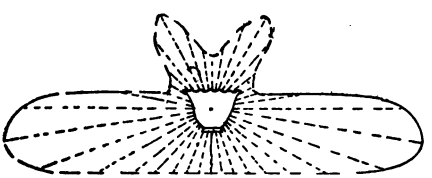

Fig. 31

FIGURE 32

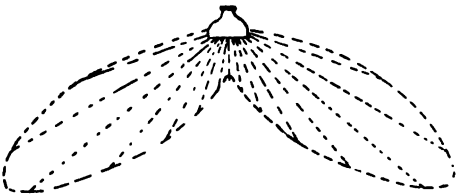

FIGURE 33

which is governed by the height at which the unit is suspended.

Figure 25 gives a curve illustrating the necessary relation of candle power at different angles necessary to produce illumination of equal intensity on a horizontal plane.

Of the cuts Figures 26 and 27 represent Holophane spheres and hemispheres respectively.

Figures 28 and 29 show reflectors suitable for side brackets which would otherwise throw much of their light against walls.

Figure 30 shows a strongly concentrating reflector.

Figure 31 a gas outlet, and Figures 32 and 33 show window and street lighting reflectors.

All of these figures, with exception of number 32, which is taken from catalog of National X-Ray Reflector Co., are of the prismatic glass type as made by the Holophane Co.

The performance of standard extensive, intensive and focussing reflectors is given in chapter, "Illumination Tables."

CHAPTER IX

LOCATION AND HEIGHT OF LAMPS

Lamps may be arranged either for local or general lighting. The best present practice is to provide a nearly uniform illumination over the whole area and, as far as possible, to avoid the use of local lamps. A system of general illumination gives better diffusion and in most cases will avoid much of the eye strain.

Where it is necessary to provide local illumination in addition to the general illumination, the lamps should be well shaded and care should be taken that the contrast between the local illumination and the general is not too great. Where lamps are used for local lighting it is best to arrange to have the light come from the left and slightly from the rear of the desk or work bench. For left handed writers it should come from the right but always should be so arranged that the glare which is unavoidable from lights hanging in front of parties be avoided. Light reaching the eye from an unusual direction is apt to cause eye strain and be very uncomfortable.

For the general lighting of rooms having only one outlet the lamp or fixture is placed in the center of the room and unless there are special reasons against this it will do very well. Where more than one lamp

or fixture are used for general lighting the space is usually divided into equal parts as near perfect squares as possible and an outlet placed in the center of each space. This method will usually give a fairly even distribution of light if lamps are hung at the proper height. In large spaces divided into many squares the spaces near the wall, if walls are dark, will not receive as much light as the center spaces, but if walls are of light color the reflected light will about make up for the deficiency. It is sometimes best in such places to make the distance from wall to first row of lights less than half the distance between lamps as it otherwise would naturally be.

In many places it is advisable to place rows of lamps over machines where the light is most needed and let aisles and other places where no close work is done take care of themselves.

Where large floor spaces are illuminated by many lamps the intensity on the working plane is nearly independent of the height at which lamps are suspended. This is, however, a very difficult matter to drum into the heads of workmen in such places simply because each can improve the lighting at his own station by bringing his lamp down closer to his work. This improvement is, however, while other lamps are hanging high, at the expense of the lighting of his neighbors because his lamp having been brought down no longer spreads light to them; thus each one will apparently improve his intensity by bringing his lamp as low as possible which improvement will be lost when his neighbors bring down their lamps. Finally when all are brought as low as possible, all workmen

are compelled to be satisfied because lamps can be brought no farther down. A certain shipping room is called to mind where upward of 600 incandescent lamps are spaced about 6 feet centers and barely 7 feet above floor. All of these lights are in the line of vision of every workman on the floor whenever he looks up and the illumination is very poor but owing to the reasons given above the men will have it no other way.

It is common practice to space outlets so that the distance between lamps is from 1 to 2 times the height above the working plane. For each type of reflector there is a definite ratio between the distance apart of the lamps and the minimum height above the working plane that lamps must be hung in order to obtain approximately uniform illumination over the whole surface. The hanging of the lamps at a greater height will not reduce the uniformity of the illumination but will to a small extent reduce the intensity. This reduces the glare but leaves a smaller part of the light to reach the sides of machinery or counters. In factories and for some classes of office work a certain amount of sidelight is essential to good illumination. In such places the height of lamps may be less than the height necessary to obtain approximately even illumination or reflectors with a wider distribution of light may be used.

When Holophane reflectors are used the spacing recommendations are as follows:

Type of reflector	Height above working plane
Extensive	1/2 times distance between lamps

Intensive .....4/5 times distance between lamps
Focusing .....4/3 times distance between lamps

When lamps are placed in rectangles the average of the side should be taken as the distance between lamps. For other types of reflectors data can be obtained from the manufacturers as to proper spacing.

For rooms 12 feet square or smaller one lamp or fixture will usually be sufficient for general lighting unless the room is used for some special purpose. For larger rooms it is usually best to provide two or more outlets unless ceilings are very high. In large stores where bays are from 20 to 25 feet square it is common practice to place one outlet (cluster or arc lamp) at the center of each bay.

In large industrial plants the bays are sometimes very large and often the available places for supporting lamps are far apart; in other places lamps must be hung over cranes. Such places are generally hard to illuminate properly and as a rule require the use of large units.

In places where there is much dust and dirt the fact that arc lamps require frequent trimming is often an advantage because globes are apt to be cleaned at the time of trimming. The fact that incandescent globes and reflectors are not kept clean forms the basis for much very poor illumination.

In large places having many lights the lamps should be hung higher than in small rooms, otherwise the effect of glare will be greater.

Rooms with dark walls and ceilings require closer spacing of lights in order to give proper diffused light because the reflected light is less.

If too much of the light comes from a horizontal direction the shadows will be too long to give a good view of objects, while if the light comes too much from the vertical objects are apt to appear flat and indistinct.

Desks and work benches, when very smooth and bright will often give strong enough reflection to be annoying. This effect is frequently noticed directly under fixtures having a number of lamps and hung low. The use of bowl frosted lamps or enclosing globes will usually remedy this defect.

Buildings with large window space require more light than darker ones on account of the comparison with good daylight and on account of the loss by absorption in the windows. This loss can be reduced by the use of light colored shades.

Where lights are used only on dark days a higher intensity should be calculated for than for use at night.

CHAPTER X

COLOR OF LIGHT

As the eyes are used mostly during the day it is probable that the light which is the nearest approximation to daylight is best for the eyes. The color of daylight, however, varies widely, not only from morning to night, but also on different days so that the eyes are accustomed to and can get along comfortably with any color from orange to white. Any shade between these colors will be satisfactory in places where it is not necessary to match or judge colors. About the only electric lamps yielding a light which is not suitable for ordinary purposes is the mercury vapor lamp (glass tube) and the enclosed arc lamp when used with a very long arc such as the 220 volt direct current lamp. The colors of these lamps produce effects that are disagreeable to many people.

In many places some attention is paid to special colors of the light it being thought desirable to have the color of light harmonize with the surroundings.

In places where colored fabrics are displayed the light should be as white as possible. Most artificial lights produce color distortion the changing of blue to green being about the most noticeable effect, but

pink and green colored fabrics are usually changed more or less when viewed by artificial light.

In all places where color value is of importance, the color of the walls and ceilings is also of importance as the color of the reflected light is modified by the color of the reflecting surface. In indoor illumination there is often color enough on walls and ceilings to materially affect the light and this may be the cause of failure of a system of lighting if proper consideration is not given to this point.

A light having an excessive amount of the rays of any color can be made whiter by using its complimentary color on walls, ceilings, or other reflecting surfaces, or for enclosing globes.

This, however, only subtracts the rays that are absorbed by the reflecting surface or enclosing globes and can never add rays that are lacking in the source of light. If a source of light is lacking in certain colors, any attempt to improve the color simply reduces the amount of light overmuch. The mercury vapor lamp is a good illustration of this.

Two spectral colors that will produce a white light are said to be complementary.

Red is complementary to bluish green.

Orange is complementary to greenish blue.

Yellow is complementary to blue.

Greenish yellow is complementary to violet.

The Moore tube with carbon dioxide gas in tube gives a color that is practically the same as daylight and is used in textile factories for matching the most delicate shades.

The intensified arc lamp gives a color that comes

next to that of the Moore tube and can be used with good results in nearly all places. A special type is now on the market which is thought to be equal to the Moore tube.

The open arc and the magnetite arc lamp give very good white light, but for other important reasons are not suited for indoor lighting.

The tungsten lamp gives a nearly white light and while inferior to the intensified arc is used in dry goods stores and similar places with very good results.

The Nernst lamp when used with a light blue alabaster enclosing globe is of about the same color as the tungsten lamp.

The enclosed arc lamp with 70 or 80 volts at arc gives a bluish white light. Where color of the light is important it is customary to use outer and inner opal enclosing globes. So equipped, these lamps may be used in dry goods and department stores, but are still inferior to tungsten or Nernst lamps.

The tantalum, graphitized and carbon filament lamps have color values in the order named. Any attempt to improve the color of the carbon filament lamp by the use of colored or tinted enclosing globes or shades results in the loss of a large amount of light.

Tabulation of colors of electric and other sources of light.

Moore tube (carbon dioxide gas)	White
Intensified arc	White
Magnetite arc	White
Open arc	Nearly white
Tungsten lamp	Nearly white

Nernst lamp .....Nearly white
Enclosed arc (short arc).....Bluish white
Tantalum lamp .....Pale yellowish white
Gem lamp .....Pale yellowish white
Carbon lamp .....Yellowish white
Regenerative flame arc .....Yellow
Flaming arc.....Variable, depending upon carbons
Mercury vapor lamp (Glass tube).....Bluish green
Mercury vapor lamp (Quartz tube).....
Enclosed arc (long arc).....Bluish white to violet
High sun .....White
Low sun .....Orange red
Sky light .....Bluish white
Welsbach mantle .....Greenish white
Gas, ordinary burner.....Pale orange yellow
Kerosene lamp .....Pale orange yellow
Candle .....Orange yellow

CHAPTER XI

CHOICE OF LAMPS

In the selection of lamps for use in certain places the temptation to give too much attention to cost and not enough to other considerations is very great. In this connection an old motto: "Quality is remembered when price is forgotten," is well to be borne in mind. Nothing can be truer; for the unsatisfactory lamp or the poor job of installation is constantly before one's eyes and constantly forced upon one's attention, while the original cost, or the slight saving is soon lost sight of.

In many cases the height of the ceiling will practically decide the type of lamp to be used as, for instance, with low ceilings lamps of small candle power are nearly always indicated.

In places where lamps must be hung high to clear cranes, etc., large units should be used. Large units are to be recommended in all places where there is sufficient elevation to allow of sufficient spreading of light. The original cost is less and also the cost of maintenance.

In flour mills, foundries and other dusty places where all objects soon assume the same color, a light giving sharp shadows is preferable, while in drafting

rooms and similar places a well diffused even light is necessary.

As a rule lamps requiring skilled attendance should not be used in small establishments where usually the proper facilities for such work are not at hand.

The question of reliability should be given particular attention especially in stores and public places.

In other places the fire risk makes necessary the use of lamps that can be enclosed in vapor tight globes.

Steadiness and absence of flicker are of prime importance where close work is necessary.

In places already wired the location and capacity of outlets have often a limiting influence upon the choice of lamps.

In many places a very white light is necessary while in others such as residences and public assembly halls a mellow light is sometimes preferred.

As a rule lights having a large number of red rays should not be used except for advertising or display purposes.

Blue and violet lights are disagreeable to many people.

The use of lights of different color in the same room should as far as possible be avoided and when so used should at least be placed out of the line of vision.

The efficiency of electric lamps should be compared on the basis of lumens per watt at lamp terminals or watts per mean spherical candle power.

The efficiency of incandescent lamps is generally given by makers in watts per mean horizontal candle power.

The efficiency of Nernst, mercury vapor and arc lamps is generally given in watts per mean lower hemispherical candle power.

Arc lamps are sometimes rated in watts per maximum candle power and the power used is often only that consumed at the carbons and does not take into account that used in magnets and resistances.

Arc and Nernst lamps are often rated on the light given out with clear globes although the use of such globes is very seldom advisable.

In view of the above considerations it is necessary to use considerable caution and judgment in the choice of lamps and where the installation is of sufficient importance personal tests should be made.

The efficiency of electric illuminants varies widely and any values given for comparisons must be used with caution. Table gives what is believed to be a fair approximation of the efficiency of various illuminants.

Type of lamp.	Watts per mean spherical c. p.
Carbon filament	3.60 to 5.00
Gem	3.00 to 3.45
Tantalum	2.25 to 2.70
Tungsten	1.45 to 1.80
Nernst lamps	2.00 to 2.50
Open arc, direct current; with clear globes	1.20 to 1.30
Open arc, alternating; with clear globes	1.70 to 2.00
Enclosed arc, d.c. multiple, opal inner and clear outer globes	2.60 to 3.00
Enclosed arc, d.c. multiple, opal inner and outer globe	3.00 to 3.50

Enclosed arc, a.c. multiple, opal inner and clear outer globe ..... 2.80 to 3.20
Enclosed arc, a.c. multiple, opal inner and outer globe ..... 3.50 to 4.00
Enclosed arc, d.c. series; with clear globes. 1.80 to 2.20
Intensified arc, opal outer globe..... 1.80 to 2.00
Luminous arc, series; with clear globes.. 1.30 to 1.50
Luminous arc, multiple; with clear globes. 1.60 to 1.80
Flaming arc, series; with clear globes.... 0.25 to 0.35
Flaming arc, constant potential, with clear globe ..... 0.30 to 0.60
Regenerative flaming arc, series with opal outer globe ..... 0.30 to 0.45
Regenerative flaming arc, multiple, opal outer globe ..... 0.40 to 0.60
Mercury vapor lamp ..... 0.70 to 1.00
Mercury vapor lamp, quartz tube..... 0.25 to 0.30
Moore tube ..... 1.50 to 2.50

CHAPTER XII

CHOICE OF FIXTURES

Nearly all electric lights used in residences, assembly halls and other places where appearances are at all considered are supported on some sort of fixture which may take the form of a center chandelier, side bracket, standard or table lamp. As these necessarily become prominent parts of the furnishings of the rooms it is desirable that they should be made as pleasing as possible.

While no attempt is to be made in these pages to define closely what is beautiful and what is not it will still be of value to note the principal points to which all things that are to be considered beautiful must conform.

Nothing can long be considered as handsome or beautiful that is not useful. This utility may be considered from three different points: It may consist entirely in practical utility the fixture being merely a substantial and suitable support for the electric light.

2nd. It may serve the purpose of relieving us of the sense of monotony or sameness, i. e., be distinctly different from other fixtures thus pleasing us by the variation.

3rd. It may be the means of conferring some degree of distinction upon the owner, by its uniqueness, elaborateness, expensiveness, or other special features. The more difficult these may be to reproduce the greater will be the value.

All of these points may of course be combined in one fixture and the more naturally and unostentatiously the last two can be made to appear to serve the purpose of practical utility the greater will be the actual and lasting beauty of the fixture.

No matter how much, to obtain variety, the form and the nature of material used may vary it must always be arranged so as apparently to serve the purpose of practical utility.

No fixture should be chosen merely for its own appearance, but the surroundings in which it is to be used should be duly considered.

Elaborate fixtures should be used only where the cost or trouble of keeping them properly cleaned will not be burdensome.

Elaborate fixtures especially should never be made up of cheap material or construction. Cheap imitations or pretenses are always offensive.

On richly ornamented fixtures the lights should be so placed or shaded that they will not cast objectionable shadows on the ornamentation or blind the observer and thus obscure the ornaments. Some indirect lighting is very useful in connection with such fixtures.

Large fixtures with wide spread arms should be equipped with many small lights rather than a few of large candle power and should be fitted with

diffusing globes. A number of objectionable shadows will be cast if these precautions are not observed, unless the fixture is hung quite high.

Except in special cases such as occur in the illumination of long halls and corridors, lamps should either hang pendent or be placed upright.

Fixtures used in ordinary rooms should be conspicuous neither for elaborateness or cheapness.

Fixtures in residences and similar places should usually be hung with the lowest part from 6½ to 7 feet above floor.

So-called art domes are now often hung very low especially in dining rooms. This is a fad which cannot be recommended from any point of view and fixtures so hung must sooner or later become annoying.

The lights under art domes should be equipped with reflectors which permit only sufficient light to pass upward to show the colors. The dome itself will generally be a very poor reflector, especially the reds and greens absorb nearly all the light.

A certain degree of attention must be given to fashion. But one should keep a middle course and test every new form by the points of practical utility and avoid freakish forms and the designs that are too much used.

Each fixture should be tested for mechanical strength and to see that all burs or fins that may injure the wire are removed. All threads should be tight and there should be no loose wabbly parts anywhere.

Large fixtures containing a number of lights should

be arranged on several circuits so that part of the light may be cut out when not needed.

All joints should be examined to see that they are properly soldered and taped.

Solid wire should not be used in connection with chain fixtures.

All fixtures should be equipped with insulating joints.

CHAPTER XIII

INDIRECT LIGHTING

With this method of lighting the lamps are concealed from view so that no direct light reaches the eye of the observer all of it being thrown first upon the ceiling and from there reflected back. This system is also spoken of as subdued or inverted lighting. Obviously this method of lighting should not be used where walls and ceilings are of a dark color. Especially should the ceiling be of light color. The principal objects of this system of lighting are: to prevent the bright light from striking the eye and to secure even illumination. Both of these conditons are more difficult to obtain with low ceilings by ordinary lighting than with high and therefore inverted lighting is especially well suited to low ceilings. The diffusion by this method is excellent, and it has made many friends. It is considered by many that with this system of lighting a higher intensity of illumination is required than with direct lighting; but this no doubt depends upon color of walls more than upon anything else. If walls are of light color the point at which light is likely to be most used may be the darkest part of the room and thus the eye may be denied the relief otherwise obtained when looking up

from work. Another objection to the system is in some cases the total absence of shadows and in other cases objectionable shadows cast by fixtures. Both of these objections can, however, be overcome by care in arrangement of the lighting. The placing of all lamps in the four upper corners of rooms is apt to give an entirely shadowless effect which is undesirable and has been much criticised.

The efficency of the system is from 50 to 60 per cent of direct lighting when ceilings are of suitable color. The losses are due entirely to absorption. The height of ceilings does not materially affect the results as the law of inverse squares does not apply here as has been pointed out before.

It is important to arrange fixtures in such a manner that the reflection from ceiling to table may be as direct as possible as that part of the light which is thrown against walls before reaching the working plane is subject to double or treble absorption.

Indirect lighting is arranged either by special fixtures designed for that purpose or by means of "cove lighting," which consists of lights placed on top of projections such as cornices, back bars or tops of shelving and fixtures in stores, etc.

The more efficient of these two systems is generally that of the special fixtures because these may be so designed as to throw the light from ceiling directly back to the working plane, whereas with cove lighting double reflection before reaching the working plane is often unavoidable.

To obtain satisfactory results with indirect lighting it is necessary to know the exact characteristics

of reflectors and lamps. If these are not known experimenting must be resorted to to find the proper spacing and height at which they are to be placed.

Following are the recommendations of the National X-Ray Reflector Company for units considered.

TABLE SHOWING DISTANCE FROM CEILING TO TOP OF REFLECTOR IN ROOMS OF VARIOUS SIZES

DIMENSIONS OF ROOM	HEIGHT OF ROOM	TYPE OF REFLECTOR	DISTANCE TOP OF REFLECTOR TO CEILING INCHES
10 x 10	8.5	E 100	12 *
10 x 10	8.5	E 200	12 †
10 x 10	9.0	E 100	12 *
10 x 10	9.0	E 200	16 †
10 x 10	10.0	E 200	18
10 x 10	11.0	E 200	12
10 x 10	12.0 and up	E 200	12 See note A
15 x 15	8.5	E 100	12
15 x 15	9.0	E 100	16
15 x 15	10	E 100	20
15 x 15	11	E 100	12
15 x 15	12	E 200	42
15 x 15	13	E 200	30
15 x 15	14	E 200	19
15 x 15	15 and up	E 200	12 See note A
20 x 20	8.5 to 10		See note B
20 x 20	11	E 200	41
20 x 20	12	E 100	34
20 x 20	13	E 100	22
20 x 20	14	E 100	12
20 x 20	15	E 200	62
20 x 20	16	E 200	49
20 x 20	17	E 200	37
20 x 20	18	E 200	25
20 x 20	19	E 200	14
20 x 20	20 and up	E 200	12 See note A
24 x 24	8.5 to 12		See note B
24 x 24	13	E 100	53
24 x 24	14	E 100	43
24 x 24	15	E 100	31
24 x 24	16	E 100	20
24 x 24	17	E 200	76
24 x 24	18	E 200	70
24 x 24	19	E 200	58
24 x 24	20	E 200	46
24 x 24	21	E 200	37
24 x 24	22	E 200	24
24 x 24	23	E 200	12
24 x 24	24 and up	E 200	12 See note A

*Light Walls †—Dark Walls

NOTE A.—Large rooms of this height and higher should not be subdivided into such small squares as this.

NOTE B.—Rooms of these dimensions within these height should be subdivided into smaller squares if uniform illumination is wanted.

These tables are instructive not only in regard to the special reflectors considered but also in regard to others with which it may be necessary to experiment. Note what a large difference in the height becomes necessary in some cases with only a comparatively slight change in size of rooms.

While the most economical results are obtained by the use of special fixtures suspended in rooms, more pleasing effect is often obtainable with "cove lighting." With this method it is possible to conceal all evidence of artificial illumination. To obtain good results in this manner it is, however, necessary to arrange the whole installation so as to be quite adjustable. The reflectors should be so placed that they can be tilted in any manner desirable. If conduit construction is used open in the coves and an outlet box provided for the mounting of each socket it will be possible to tilt each lamp independent of the other and secure a very even illumination of ceiling. Individual reflectors for each lamp should be used and this will make possible great nicety in the distribution of light. Cleanliness of lamp reflectors or ceiling is essential to indirect lighting.

A semi indirect system is sometimes used. With this system the lamps are placed inside of opal or other glass hemispheres which are open at the top. Part of the light is thrown downward through the glass and part of it upward and reflected back from the ceiling. Very pleasing effects can be obtained in this manner.

A perfect system of illumination requires more shadows than are generally cast by indirect lighting

and it will always be well to provide a little direct lighting with it. The efficiency of semi-indirect lighting is higher than indirect lighting.

Indirect systems of lighting are more affected by color of walls and ceilings than direct systems. The ceiling especially is of great importance. While white is the best reflecting color, it may at the same time be objectionable in some cases where it is continually in the line of vision. Gray is often taken as a light color but its reflecting value is low.

Cream or ivory colored walls are well suited to indirect lighting. Tints which contain yellow or pink are also not very objectionable. Browns, reds, greens, dark yellows or all dark appearing colors are poor reflectors.

Some very elaborate tables of coefficients of reflection have been worked out but the designer of illumination should be warned against allowing too much for light colors. As a rule light colors darken very fast from dirt and decorations are frequently changed.

A system of lighting calculated as barely sufficient for light clean walls would become very unsatisfactory if the decorations were changed to dark colors.

In any important installation of lighting it is always best to arrange sufficient circuits so that none of them will be fully loaded. This will enable candle power to be increased or decreased in any part of the room as may seem desirable.

CHAPTER XIV

PRACTICAL CONSIDERATIONS

APARTMENT BUILDINGS

Circuits.—If it is the plan that tenants shall pay by meter for their illumination, meters should be located in the basement. This will avoid annoyance from humming of meters and also from meter readers and trouble men. For the smaller apartments equipped with not more than one circuit the branch cutout should also be in basement.

With larger installations branch cutouts may be placed in kitchen. If light is included in rent, risers are preferably run in front of rear halls and cutouts located there. Sometimes two sets of risers are run in such a manner that neighboring apartments are not on the same mains and in case of accident to part of the system there is less anxiety among tenants when they notice adjoining apartments still illuminated.

Stair and Hall Lights.—These may be arranged so as to be controlled by janitor in which case switches should be placed in basement; or they may be arranged by means of commutating switches so

that each tenant can turn lights on or off at any part of stair or hall.

Where lights are to be kept burning all night some saving may be accomplished by providing resistance to be cut in series with circuit at stated time, thus allowing bright illumination in the early part of the evening and reduced illumination later. Such resistances may be under control of time switches.

It is advisable to arrange stair and hall lights so as to be independent of main fuses supplying apartments so that in case main fuse blows the stairways will not be dark.

A small candle power lamp should be installed at each floor. In all public places where lamps are likely to be stolen, the use of low voltage lamps two or more in series is some protection. Such lamps cannot be used on ordinary circuits.

Parlor—Drawing Room—Library.—The main illumination of this room is usually obtained by means of chandelier located exactly in center. The number of sockets on such chandelier depends entirely upon how much owner is willing to expend for display.

If walls and ceilings are highly decorated, or if it is desired to exhibit works of art on walls, inverted lighting may be recommended, but there should be direct illumination for reading also. One lamp and intensive reflector at bottom of chandelier is recommended.

Side brackets are often installed on both sides of consoles or mantles and may be useful at times for

individuals to read by, but they are of little use for the general illumination.

Such brackets or receptacles may be located so as to be convenient for piano or table lamps.

Where expense is not too much considered a few special outlets near floor will be advisable for heaters, etc.

In library a light arranged to illuminate titles of books in cases will be useful.

Provide switches suitably located for all center fixtures. Provide key sockets for all lamps.

Dining Room.—It is customary in many places at present to locate the main dining room light in center of room and mount it very low, not more than about 5 feet above floor. This is a fad probably born of the desire to place the socalled art shades where they can easily be seen. From a practical point of view, nothing more unsatisfactory could well be devised. The net results are: Very uneven illumination of table, bright light always in line of vision, thus having a more or less blinding effect, very unsatisfactory conditions if light is to be used for reading, and if table happens to be moved as for cleaning great liability to accidental interference with fixture. Sooner or later this arrangement will become so annoying that it will be raised to proper height above floor.

The dining room fixture may well be equipped with receptacle for chafing dish, etc. This should hang by cord in center so as to reduce jarring of fixture to a minimum.

Four or more lights are often arranged at intersec-

tions of beam ceilings. These contribute nicely to the general illumination but very little where that illumination is mostly needed. If used at all, lamps should be of low candle power and frosted or provided with shades so the bare lamp may not be visible.

In order to show off silver ware, table linen, etc. to the best advantage, a strong light should be concentrated upon the table and the rest of room left rather dark. Inverted lighting can therefore not be recommended, although where room is also used for other purposes a chandelier equipped for both kinds of lighting will be useful.

Receptacles on walls will be useful for fan motors, plate warmer, chafing dishes, etc.

Side board or buffets are often fitted out with special light.

Bed Rooms.—The satisfactory lighting of a small bedroom in which only one outlet is to be installed is a difficult matter. Many of them are now lighted by center fixture, but a center fixture should not be tolerated at all unless it is necessary the room should have the appearance of a drawing room. The light from a center fixture is continually in the eyes of sick persons lying in bed and always liable to be accidentally struck by persons dressing. Except for reading it is also the most inconvenient location that could be given to an ordinary light.

In cases where a center outlet already exists the best method of obtaining good illumination for all purposes is by means of indirect lighting, the fixture hung high. This is practicable only if ceiling of room

is light, but if light decorations are chosen, a shadowless good general illumination can be obtained which will be useful for dressing or shaving in any part of room.

By all means avoid as much as possible the use of special portable brackets, shaving mirrors, etc. The cords necessary with such devices are always unsightly, likely to cause trouble or fire and often unpleasant interviews with inspectors.

If only one bracket is to be installed it should be located so that head end of bed may be on one side of it and dresser on the other. The same light can then be used for dressing and for reading in bed and the outlet will also be convenient for connecting heating pad.

A dresser should really be equipped with three lights one at each side and one at top, high enough to be used for hair dressing. The two side lights should be about average height of face so as to give good light on all parts of face for shaving. As these three lights will be quite close together the expense of installing them will not be great.

In all bedrooms the location of lights should be such that they will not cast shadows of persons in room on windows. Shades are not always opaque.

A separate circuit for flat iron or heater will be very convenient in most bedrooms.

Place switch convenient to entrance.

Bath Rooms.—There can never be an excuse for center fixture in bath rooms. The illumination should be by means of brackets arranged to light up wash stand mirror. One light is sufficient although two are

much better and the ideal illumination for shaving and dressing would be obtained by the use of four candle power lamps, one at top, bottom and each side of mirror, placed far enough away so light will not fall directly in line of vision when using mirror.

As bath rooms are usually small and decorated white, the reflection adds greatly to the intensity with the result that there is often too much light which makes other parts of house seem poorly lighted.

Kitchen.—In the ordinary kitchen one light on center fixture is usually provided. As walls are generally light colored the reflection illuminates the shadows cast by persons working with face toward wall and the center location is not very objectionable. It is best to have the light mounted high and as far as possible away from range to avoid grease. If walls are dark the light should be over sink and work table if possible. In some cases more than one light will have to be provided.

As much ironing and pressing is often done in kitchen a separate circuit for flat iron should be run.

Closets.—Each closet should be provided with light for convenience as well as to lessen the fire hazard due to the use of matches. The light should be placed on wall convenient to door, rather than on pendant cord.

Laundry.—Here one or more lights should be placed directly over wash tubs. Other lights should be placed convenient for ironing boards. It is customary to arrange all of these lights on circuit with hall and stair lights, although in some cases they are arranged to be fed only through tenant's meter. The

complications introduced by this method are, however, hardly worth while.

Storage Rooms.—Although in storage rooms very little light is required, it is well to provide sufficient so as to make the use of matches unnecessary. If in storage rooms, basements, attics, etc. there is not sufficient illumination, janitors will soon have flexible cord run all over the places. This will introduce quite a fire hazard and can be avoided by supplying light where needed.

ARCADE.—The illumination of arcades should be kept low, otherwise it will deaden the effect of show window illumination. Place lights as much as possible where they will not interfere with show windows. Much of the window illumination will aid in illuminating the arcade. One half to one foot candle is sufficient illumination.

One row of 25 watt mazda lamps placed 12 feet apart will give an illumination ranging from 1.51 to .40 foot candles if equipped with Holophane extension reflectors and placed 10 feet above plane illuminated.

ARMORY.—The principal part of an armory is the drill hall. This requires an illumination equal to about 2 or 2.5 foot candles. This is best obtained by placing large units either arc, Nernst or incandescent lamps sufficiently high so as to procure even diffused illumination over the whole floor.

As it is necessary to be able to overlook the entire floor it is of special importance to keep all lights high enough so they will be out of the range of vision.

ARTISTS.—Artists as a rule require adjustable light

and the only practical illumination for easel work is by means of pendant cord. For color work of this kind the mazda lamp is the most suitable.

The intensified arc is better and the Moore tube best of all for color work but as these come only in large units there is not that adjustability which is necessary where many people work together as in portraiture shops and where many of them have defective eyes from close application.

Where only a few artists are at work the intensified arc or the Moore "window" may be used to advantage.

For artists working in black and white only, the Cooper-Hewitt is also useful.

Each artist should have a 25 watt mazda lamp at his disposal or the general illumination should be equivalent to about from 5 to 8 foot candles.

Control mazda lamps by pendant switches hung independent of socket.

ART GALLERIES

Statuary.—All white statuary should be illuminated from above by several sources of light placed as high as practicable. An illumination equal to 2 foot candles will be sufficient. Bronze statuary will require a much higher illumination and 8 foot candles can profitably be used.

As all statuary is of a single color the aim must be to produce some shadow effect and therefore the light must not be too much diffused.

Clusters or large units of mazde lamps hung at ceilings are best.

Paintings.—Two methods of illuminating paintings are in general use: One consists in placing rows of lights so as to face the picture without being visible to the observers and the other makes use of Holophane or opalescent spheres to reduce the brilliancy of the source of light sufficiently so as not to be very annoying to the eye. Holophane spheres designed to throw most of the light in a horizontal direction are very serviceable. Line-o-lites are also used as well as Nernst lamps.

For color value the Moore light is undoubtedly the best, and next to it comes the mazda lamp. The latter is most serviceable for general purposes. Arc and Nernst lamps are sometimes mounted above ground glass so the lamps themselves are not visible.

To obtain the best effect of many paintings they must be viewed from a distance and a very good illumination is essential. At least 5 foot candles should be provided.

In large low rooms rows of bare incandescent lamps throwing light directly upon the pictures are probably best.

Many exhibition rooms are too small to admit of this arrangement and one of the other methods must be used.

Indirect lighting is also very useful.

AUTOMOBILES

Interior.—The interior may be lighted with series or multiple lamps. In the case of electric machines the full voltage of the battery may be utilized and ordinary multiple lamps provided.

For other machines small battery lamps are used. These may be of any voltage desired and either series or multiple. They are sometimes run from storage batteries and also from dry batteries. It is not advisable to use more of these lamps than are necessary. They are comparatively expensive and their life is short. Do not attempt to run lights from spark battery.

Whether electric illumination is used in automobile or not, a special battery lamp which can be attached to battery in case of an emergency for repairs will be found very convenient.

BALL ROOMS.—A general illumination of about 2 to 4 foot candles is recommended. Place lights high so as to be out of the general range of vision. Provide receptacles for musicians' use.

BANKS.—Here a general illumination of 3 to 4 foot candles is recommended. This will have to be helped out by individual lights at many of the desks.

In the public part of banks the lights are usually arranged on large ornamental fixtures hung high. The illumination here is not much used.

BARBER SHOPS.—Good illumination of barber shops can be obtained by clusters or lamps of fairly large candle power placed close to the ceiling and a little to the rear of chairs. Placed this way the light will not be forced into the line of vision of customer and still shine directly upon his face. Directly in front of chairs are always large mirrors which reflect much of the light upon the lower part of his face. The more reflection from all sides there can be arranged for the better it will be. Light colored decorations will greatly assist in this.

Lamps encased in diffusing globes may be arranged along front of mirrors and assist somewhat but in barber shops as much as in any other place a light in the line of vision is of very questionable utility. The brightest light should always be at the point where work is done.

BARNS.—Place no lights directly in front of horses. Place them behind horses and keep high.

Avoid use of brass shell sockets in horse barns.

Use weatherproof construction in carriage wash rooms.

Place lights in all dark corners that are used, thereby avoiding the use of matches.

BILL BOARDS.—A very bright light of about 8 to 20 foot candles is often used. Lamps are fastened inside of reflectors so arranged as to throw light upon the board without the source being at all visible to the observer.

BILLIARD HALLS.—A general illumination of about 0.8 to 1 foot candles is recommended for the hall. Good illumination of table requires about 4 to 5 foot candles.

A cheap installation can be arranged with only one light per table, but for good results there should be at least two. These should be below the level of men's eyes and shaded. The candle power of lamps can then be varied to suit conditions.

From two to four lamps per table are provided. The lamps and reflectors should be so chosen that the light on table will be uniform and neither the players at this table or at any other obtain a view of the bare lamps.

It will be very convenient to have a switch provided to control all of the lights at any table.

Bowling Alleys.—Illumination equal to 1.5 to 2 foot candles is recommended for the alley and about 4 for pins.

Cover lights so they will not be visible.

Churches.—Many of the larger churches require a lighting equipment for colors, dimmers, etc., very similar to that of theatres. In choirs lofts and at altars pockets for special lights are often needed.

Very pleasing illumination, especially where ceilings are highly decorated, can be affected by inverted or cove lighting; the lights not to be placed too near the ceiling.

In churches especially the glare of direct lighting should be kept out of the line of vision of not only the audience but the speaker as well. This is more important here than in theatres, because in these the actors are most of the time facing brilliant spot lights and desire all the light possible to be thrown upon themselves from in front.

In churches the light sources should not be easily visible to any one. This leaves the choice practically between deep reflectors of some kind or indirect lighting, although large prismatic spheres or hemispheres can be made to give good service.

Churches should particularly be conspicuous for the absence of studded lights so common in most public halls and which seem to be provided more to show that the owners have "Money to burn" than to provide illumination.

Chemical Works.—In such places fumes and de-

posits often have a very injurious effect upon certain metals. To avoid trouble, before wiring in such places, consult with experts in charge relative to effects on copper, rubber, etc.

COURTS.—In handball courts the best illumination is obtained by means of cove lighting, throwing the light up to the ceiling. One should not be compelled to look into strong light while following a ball through the air. This light can be further augmented by lamps placed under galleries or along walls very low and shielded. However placed, lamps should be enclosed by wire mesh. A brilliancy of 8 to 10 foot candles is recommended. The indirect lighting should not be entirely shadowless.

DEPARTMENT STORES.—In such places huge floors constitute a single room and the lighting is generally laid out in symmetrical manner so that there appears to be the same illumination throughout. This is not exactly the best practice, as some classes of goods require much more light than others.

If, however, the branch circuits are provided for, say, every four or six lights, there will be opportunity to install large candle power lamps where special brightness is required, without detracting from the general appearance of symmetry on the floor.

The intensified arc is especially well adapted for use where it is essential to bring out true color values. If Nernst lamps are used, a blue alabaster globe will improve color values. For enclosed arcs use inner and outer opal globes.

DESK LIGHTING.—Where desks are occupied during a small part of the time only, illumination by means

of individual lights at each desk is no doubt the most economical. This method of lighting is probably, however, responsible for more defective eyes than anything else in the illumination line.

A general illumination which shall suit all workers at desks is not always practical, there being a great variation in the light requirements of different people.

The best combination where economy is not too much insisted upon is a general illumination sufficient for the best eyes and individual lights of small candle power to help out those requiring more light. The ordinary desk light placed in front of occupant should not be allowed anywhere.

DINING ROOMS.—Large dining rooms with high ceilings are often illuminated by large numbers of small candle power lamps arranged in rows or circles along ceilings or friezes.

Candelabra brackets or outlets on walls or posts where tables are to be located are often used.

Floor pockets for special effects in case of banquets, etc., should be provided.

Heating circuits for chafing dishes, etc., will also be convenient. In small private dining or wine rooms avoid placing lights so that shadows of guests will be thrown upon glass partitions, and be visible from the outside.

In large dining and banquet rooms, high intensities should be provided, but the arrangement of circuits should be such that much of this can be cut out when subdued effects are desired.

EGG CANDLING ROOMS.—One light must be pro-

vided for each workman. This light must be at about the height of a man's waist and adjustable as to height and position.

Avoid running wires overhead, as the booths are sooner or later all provided with covers. Use conduit or moulding, run so as to reduce necessary length of cord to a minimum.

A 16 c.p. lamp is generally used encased in hood with only a small opening.

ELECTRIC SIGNS.—In most electric signs the letters are outlined by a number of incandescent lamps.

In order that these letters should show full outline instead of merely exhibiting lamps, the letters should be a glossy white and clean. Such letters will appear nearly as bright as the lights. Small 2 or 4 c.p. lamps are used mostly and are often wired in series. Large candle power lamps are expensive to operate, painful to look upon and the glare makes all else invisible.

Arc and Cooper-Hewitt lamps are sometimes used inside of glass signs.

The following table gives dimensions and sockets of stock letters as made by the Federal Electric Co., of Chicago, which will serve as a general guide to present practice.

Each sign should be wired so that the two sides can be separated in case it is desired to use a "flasher," thus switching out one side at a time. Sometimes flashers are arranged to flash each letter separately. Even when flashers are not used one side of sign is often switched out for sake of economy, no business being expected from that side.

FACTORIES.—Until recently it has been the general custom to illuminate workshops of all kinds by means of 16 or 8 c.p. lamps suspended by flexible cord

	10 INCH LETTERS		14 INCH LETTERS		16 INCH LETTERS 4 LAMP HIGH		16 INCH LETTERS 5 LAMP HIGH		24 INCH LETTERS	
	Sockets	Width	Sockets	Width	Sockets	Width	Sockets	Width	Sockets	Width
A	8	10	8	12½	8	15½	10	15½	11	21
B	10	10	10	12½	11	15½	13	15½	13	21
C	7	10	7	12½	7	15½	8	15½	8	21
D	8	10	8	12½	9	15½	11	15½	11	21
E	9	10	9	12½	9	15½	10	15½	13	21
F	7	10	7	12½	7	15½	8	15½	10	21
G	8	10	8	12½	8	15½	9	15½	11	21
H	9	10	9	12½	9	15½	11	15½	12	21
I	4	5½	4	6	4	8	5	8	5	9
J	6	10	6	12½	6	15½	7	15½	7	21
K	8	10	8	12½	9	15½	11	15½	11	21
L	6	10	6	12½	6	15½	7	15½	8	21
M	13	12½	13	15½	13	19½	15	19½	17	25
N	10	10	10	15½	10	15½	13	15½	13	21
O	8	10	8	15½	9	15½	10	15½	10	21
P	8	10	8	15½	8	15½	10	15½	10	21
Q	9	10	10	15½	9	15½	10	15½	11	21
R	10	10	10	15½	10	15½	12	15½	12	21
S	8	10	8	15½	8	15½	10	15½	10	21
T	6	10	6	15½	6	15½	7	15½	8	21
U	8	10	8	15½	9	15½	10	15½	10	21
V	7	10	7	15½	7	15½	9	15½	9	21
W	12	12½	12	15½	13	19½	15	19½	15	25
X	8	10	8	15½	9	15½	9	15½	9	21
Y	6	10	6	15½	6	15½	7	15½	8	21
Z	8	10	8	15½	8	15½	9	15½	11	21
&	8	10	8	15½	9	15½	9	15½	10	21
1	4	10	4	15½	4	15½			5	21
2	9	10	8	15½	8	15½			11	21
3	9	10	7	15½	7	15½			9	21
4	7	10	7	15½	7	15½			11	21
5	10	10	10	15½	10	15½			12	21
6	9	10	8	15½	9	15½			11	21
7	6	10	6	15½	6	15½			8	21
8	11	10	11	15½	8	15½			10	21
9	9	10	8	15½	9	15½			11	21
$	8	10	8	15½	8	15½			8	21
				15½						

about 7 feet above the floor. The introduction of the large unit mazda or tungsten lamp has brought about a change in this direction and the best factory

illumination is now obtained by the use of about 100 watt lamps equipped with proper reflectors and ordinarily hung as high as belting and other obstructions will permit. One such lamp to about every 300 square feet under average conditions is the illumination provided in many factories. The lights are so arranged as to throw the strongest light in places where it is most needed and if necessary for special machinery individual 8 c.p. lamps are provided. The method of illumination has the advantage that there are fewer changes in location of lights necessary when machinery is moved as is inevitable in the ordinary factory.

Where much small machinery is used and where the work is fine, it is best to have the illumination as much as possible of a general nature, but it should be obtained by lamps placed close enough together in all directions so as to avoid shadows at the different machines. Where very fine work is done it is necessary to provide individual lights for each operator. In routing machines, such as are used by engravers, it is not unusual to find two lamps mounted one on each side of movable tool and arranged to move with it.

Where cranes are at work it is necessary to mount all of the lights for general illumination very high, and here the flaming arc can be used to advantage.

If the illumination is by means of individual lamps only, it is well to avoid locating lights until machinery is installed. Experience has shown that plans are seldom reliable and often necessitate changing most of the lights when machinery is finally located.

A shadowless well diffused illumination can be obtained from mercury vapor lamps, but some men will not work under them on account of the ghastly appearance of faces.

There is much difference of opinion in regard to the usefulness of this lamp.

Run wires either between joists or along beams or walls to avoid interference from ladders, etc.

Among machinery where oil is thrown flexible cord encased in loom is preferable to re-inforced cord.

FESTOON WORK.—For special occasions, such as street fairs, holiday celebrations, etc., a very brilliant illumination over streets is sometimes provided. This

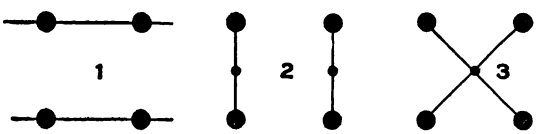

FIGURE 34

work is nearly always of a temporary nature and festoons carrying from 10 to 50 or 60 lights are often used. These are strung across streets and fastened to buildings or poles, trolley poles being sometimes used for that purpose.

The arrangement of festoons may be according to either of the three plans shown in Figure 34 or any combination of these. Where lights are strung across streets as in plan 2 the festoons are usually supported in the center so that they may hang somewhat on the order exhibited in Figure 35. The numbers 1.2, 1.3, etc., indicate the increase in length

of wire over width of street which is necessary to allow of elevating center of festoon according to the corresponding lines shown.

At street intersections the arrangement is often as indicated at 3, and if this plan is used the length of wire must be again multiplied by 1.4.

Good effects are obtained by placing lights on these festoons about 18 inches apart.

If festoons are made long enough to cross street it is not advisable to use smaller than number 10 wire.

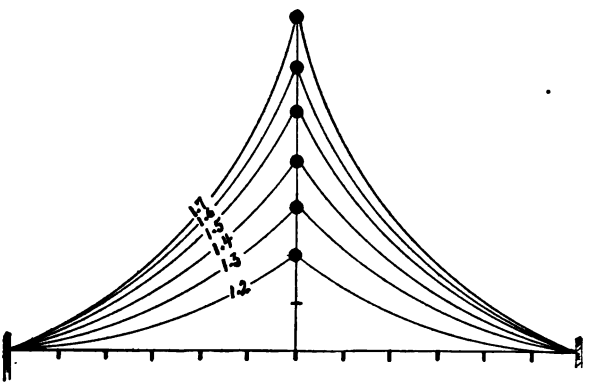

FIGURE 35

Such festoons may be obtained for rental.

FOUNDRIES.—The general illumination of foundries is usually effected by means of arc lamps or clusters on incandescent lamps. Strong shadows are very useful as all objects soon become of the same dull color.

Where height of ceilings will permit their use there is no lamp that will compare with the flaming

arc for the illumination of foundries. The yellow light given by most of these arcs seems to have the power of penetrating the dust and dirt of these places very effectively.

Where on account of cranes lamps must be hung very high, the inclined carbon type can be used to good advantage.

Arc lamps of this kind should be hung quite high. Ease of cleaning is a prime requisite on account of the smoke and dust which settle on everything. Clusters of incandescent lamps should therefore be enclosed in outer globes which can easily be cleaned. Use only clear globes.

In addition to the general illumination an individual lamp must be provided for each molder. It is not practical to provide sufficient general illumination for this work.

Reflectors as such are of very little use, unless cleaned very often, but should be provided to protect workmen's eyes against direct rays of light.

HOSPITALS

Corridors.—Only a very light illumination of .5 to 1 foot candles is recommended.

Public Wards.—Here a subdued light is recommended and it is probably best obtained through diffusing globes encasing the lights, as otherwise a strong light is unavoidably in the vision of patients. The best effects would probably be obtained by inverted lighting, the lights hung very low so as to avoid very bright spots on ceiling from which light is reflected.

Private Wards.—These should be provided by lights mounted at head end of beds and adjustable. Light should be provided with reflector so that it may be thrown upward to ceiling or upon book the patient may be reading. Never allow installation of center fixtures. Each lamp should be equipped with pendant switch by which patient may control it if permitted by physician.

Receptacle should be provided near head for use of physician or nurse in examining patient.

Operating Rooms.—Operating rooms require a very bright diffused shadowless illumination. Place lights high and provide sufficient for 10 to 12 foot candles. Provide switching facilities so that illumination can be varied at will. Provide receptacles for special lights near operating table.

HOTELS.—In hotels it is advisable to arrange the lighting in such a manner that by no chance may all of the lights on any floor be out of service at the same time. Guests may often be worried by such an occurrence. To avoid this, mains may be run separately for each vertical half of building, or all of the branch circuits may be carried down to the basement. By this latter plan, as most floors in hotels are exactly alike, a straight run of wire from basement to top floor, if not more than 6 or 8 floors, catching all lights vertically above one another will make one circuit. As most rooms also contain more than one light, it will be possible to have two distinct circuits in each room and these in basement may be placed on separate mains so that the chances of any room being left in total darkness become exceedingly small.

A scanty illumination is usually provided in halls but it should be reliable. Unless one of the plans noted above is followed the halls and stairway lights should be on separate circuits.

Circuits for vacuum cleaners should be provided in halls.

For treatment of rooms, see "Apartments." Door controlled switches will be very useful.

Carriage call is often provided for large hotels.

If the expense is not prohibitive specially arranged circuits by which lights may be turned on from outside even though they are shut off from within will be very useful in case of fire. For method of running such circuits see "Modern Wiring Diagrams and Descriptions."

LIBRARY

Book Shelves.—A good general illumination by which titles of books can easily be read should be provided. Straight filament lamps with reflectors to throw light directly on books can be used to good advantage.

Reading Rooms.—It is most economical and also most satisfactory to provide only a medium general illumination of about 1 to 1.5 foot candles and strengthen this with local illumination at tables sufficient to increase intensity to 3 to 4 foot candles.

In many reading rooms a homelike effect can be produced by the use of table lamps artistically decorated. The kind of table lamp here referred to is more in the line of a fixture mounted on standard and with two or four lamps under the dome provided

with reflectors to throw the light out sideways and spread over table. In this way very good illumination can be obtained on reading matter held normal to the light. The artistic appearance of the table lamp can in this way be combined with utility. The common small table lamp should never be depended upon for illumination.

MOVING PICTURES

Exposure—Making Negatives.—For this purpose Cooper-Hewitt lamps are almost invariably used. About 50,000 c.p. are required to do satisfactory

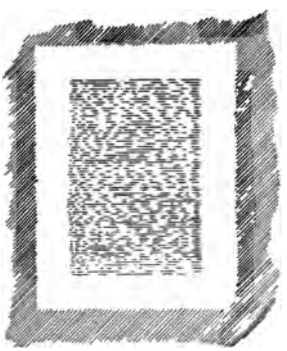

FIGURE 36

work. All of the lamps must be arranged adjustable so that the operator may obtain any desired light or shadow effect.

Exhibition.—Moving pictures may be shown in darkened theatre or in one dimly illuminated. In the latter case they are spoken of as "Daylight" pictures. The daylight pictures require the use of two

arc lamps. One of these is used only to make what is known as the "frame." This is made by focussing the lamp so as to illuminate a large square and the center of the square is protected by a shade of some kind so that it remains dark. See Figure 36

Upon this dark square surrounded by a brightly illuminated band of light the moving pictures are thrown by means of the other lamp. There is very little advantage in this method except that theatres may be illuminated, and it comes into use occasionally as a novelty. The additional cost of electrical energy is quite great, as it requires not only a second arc lamp but illumination of the house as well.

The ordinary moving picture requires only one arc lamp but should be fitted with adjustable rheostat as many films are dark and require more light than the others.

No wire smaller than No. 6 B. & S. gauge is recommended for these arc lamps as they often require from 30 to 50 amperes.

On alternating current circuits a compensator should be used to regulate the voltage, as the use of a rheostat will give enough heat to be objectionable and will consume much more energy. The use of a choke coil is objectionable on account of low power factor, and the efficiency is somewhat less than with a compensator.

Offices.—In large offices where all employes are constantly at their desks, there can be no difference of opinion as to the superiority of good general illumination over individual desk lighting and this method is rapidly superseding the old. Some pro-

vision should, however, be made to provide extra light for those specially in need of it.

In offices occupied by solicitors and others that are at their desks only for a short time per day, individual desk lighting is more economical, since only those that are actually required need be burning while otherwise the whole installation might be required to be in use all of the time.

Large spreading chandeliers are often used because of appearance, but the light coming from a number of lamps placed a few feet apart is apt to cause a number of shadows which are disagreeable. If clusters of incandescent lamps are used, the lamps should be close together, especially if clear globes are used.

In installing illumination in offices it is always advisable when possible to postpone location of lights until desks are actually located.

Never lay out illumination with the idea of using the desk lights that are placed directly in front of occupant. These are an abomination and responsible for more eye troubles than any other feature of artificial light.

Suspend lights above and slightly back of space on desk to be illuminated. For right handed people light should come over left shoulder. With light coming from front a very disagreeable glare is unavoidable.

In the best office buildings ¾ inch conduit is used entirely for all branch circuits. This gives capacity for any combination of switching and also allows extra wires to be pulled in when necessary.

In small offices outlets should be arranged along walls rather than a center outlet provided in ceiling. Always arrange lighting so it will be in harmony with windows, and furniture placed correctly for windows will also be right for artificial lights.

OUTLINE LIGHTING.—Outline lighting on buildings or structures may be for the purpose of attracting attention to the general outline or to some particular part of building.

Where merely an outline is to be formed and no particular attention given to the exhibition of details, rows of small candle power incandescent lamps will best accomplish the purpose. Unless the illumination is to be viewed from a great distance or is very high above the street 4 and 2 candle power lamps will be sufficient. Larger candle power lamps will have such a strong blinding effect as to make all parts of building invisible. Details of buildings cannot well be made visible by this kind of lighting.

Various color effects are sometimes striven for but such arrangements have more an advertising value than artistic merit.

By varying the spacings on different parts of buildings the dimensions can be made to appear entirely different and in certain cases the appearance of building improved.

The illumination of the entire surface of a building by incandescent lamps is very expensive and seldom attempted. If this is desired it is best to use large units or arc lamps. These should be suspended some distance from the building and provided with re-

flectors and so placed that most of the light comes from one direction and that it casts shadows.

Search lights are sometimes used for this purpose and where a suitable place for mounting them is available the details of buildings can be very well shown.

The main purpose of all such lighting as a rule is advertising or to attract attention during some festival. If it is to be effective it must change its form from time to time and therefore it is not wise to incur any very great expense in construction.

Special festoons and wires arranged for this purpose are on the market.

PACKING HOUSES

Throughout all buildings run a watchman's circuit controlled by 3 way switches.

Killing Floor.—These places are usually damp and a good illumination is necessary; especially for inspection.

Use large units or clusters of incandescent lamps.

Avoid high tension arcs. Avoid conduit construction in all damp places.

Coolers.—Only a medium degree of illumination is necessary but there is much steam which sometimes reduces light one half to be reckoned with.

Canning.—Good even light of high intensity is essential over work benches. In other parts of floor not much light is needed.

Inspection.—Here a very bright illumination is necessary. It is not uncommon to find rows of 16 candle power incandescent lamps spaced from 2 to

3 feet apart and hung very low so as to obtain full effect of light upon cans. Use concentrating reflectors.

Refrigerators.—Some refrigerating rooms are used for display purposes and a very good illumination is called for. Avoid porcelain sockets in cold places especially.

Place rows of lights in center of aisles above customers' heads.

Other refrigerating rooms are used merely for storage and only an indifferent illumination is needed.

Storage.—Avoid use of long drop cords. Place lamps high and control by 3 way switches if there is more than one entrance. Individual lights or small groups may be controlled by pull switches.

Lights placed from 20 to 30 feet apart are often used.

Reflectors are not used.

In addition to the above there will be found inflamable vapors, combustible dust flyings in hair, houses, etc., woodworking, paint shops, printing presses, composition rooms, etc.

PHOTOGRAPHY

Making Negatives.—In copying from drawings or paintings it is customary to use two arc lamps one at each side of picture. It is desired to have the light as strong as possible and for this reason the open arc is much in favor.

Special lamps carrying very heavy currents are obtainable for this purpose.

The Cooper-Hewitt lamp is also much in favor for portraits.

Enlarging.—This is usually carried on by means of a single arc lamp located behind a suitable lens before which the negative is placed.

Printing.—Only one lamp is used as a rule. For some classes of work the light should be well diffused. Whether powerful arc lamps or ordinary incandescent lamps are to be used depends upon the kind of paper which is to be printed.

In some kinds of work, such as ornamental glass, the light must be arranged to come from a single or point source. The negatives are usually large plates of glass and do not lie close upon the plates to be printed. A light giving source of an appreciable size would cause blurred lines under such circumstances. Reflectors cannot well be used under these circumstances and it is customary to place a circle of negatives around the arc. Arcs requiring from 100 to 200 amperes are not uncommon for this kind of work.

PRINTING

Composing Rooms.—A good general illumination should be provided in these places and the lights so placed that the brightest light will fall on such cases that need it most. In some cases it will be necessary to help out with individual lights for composers or makeup men.

There are composing rooms in which it is advisable to provide each case with a switch so arranged that compositor can operate it with his foot or arm while

selecting type so that the light will be in use only while that particular case is being used. The switch must automatically open the circuit when left alone.

Press Rooms.—Where small presses are used it is customary to arrange for one light on pendant cord for each press unless they are placed close together when larger candle power lamps may be made to do for more than one machine.

The average large press requires at least two lights. One above for feeder and one below in the bed. This latter is often omitted and an extension cord for use when necessary provided to connect to light above. The use of this extension saves only a few cents in first cost and leads to considerable waste of time and some fire hazard. It is more economical in the end to provide for a permanent light in convenient location among the working parts of press. This light should be wired for in conduit.

Many of the largest combination presses require from 6 to 12 lights distributed about the machinery. The working time of such presses is valuable and every necessary light should be provided and so installed that it can be instantly brought into use and give a minimum of trouble. Flexible conduit is freely used for this kind of work but the wires within it should have a lead casing to prevent oil from coming in contact with the rubber insulation. Around presses a good general illumination of diffused light which will reduce shadows to a minimum is desirable. Mercury vapor lamps are often used in large press rooms.

REFRIGERATORS

Only an indifferent illumination is generally required. 16 candle power lamps are often spaced about 20 feet apart and placed only in run ways.

Open wiring with weatherproof construction is preferable in all cases except where there is continual cold. In such locations ceilings often become coated to a depth of 10 or 20 inches with frost which it is necessary to scrape off from time to time and this scraping is likely to result in disturbing wires. Conduit is preferable in such places.

Use no porcelain sockets in cold places; they break very easily.

If possible arrange circuits to enter cold rooms at some distance from general entrance as at places where cold and warm air meet there is always much moisture.

Locate cutouts outside of damp rooms.

In large refrigerators circuits are apt to be very long and it will be well to use wire larger than No. 14.

Where watchmen have routes leading in at one door and out at another 3-way switches at each door will be convenient.

RESIDENCES.

For all ordinary rooms see APARTMENT BUILDINGS.

Very pretentious residences may contain billiard and ball rooms as well as special dining rooms all of which are discussed under corresponding headings.

Good residences are sometimes equipped with circuits so arranged that in case of fire or other disturb-

ance the lights in all or some of the rooms can be thrown on by a supplementary switch even though they are turned off in rooms, and occupants warned of danger.

Good burglar protection can sometimes be obtained where it is possible to locate a light so that the burglar will be obliged to show himself under the light and in front of open doors. A small candle power lamp will so blind one that it is impossible to see into dark rooms and few will run the risk of showing themselves.

A porch light is an important adjunct to any residence and should never be omitted in the lighting. It is of use not only for the lighting of the porch but as protection against burglars and holdup men. The light should always be controlled from within and so located as to illuminate the face of any one at the door and should be high enough so as not to be easily molested by outsiders.

Lower Hall.—This should be equipped with switches so placed that upon opening the door one can at once turn switch and obtain light. Where stairway leads up from main hall 3-way switch for hall light will be useful.

Nursery.—Here the main consideration should be to keep the sockets and other live parts of the electric circuit as much as possible out of reach of children. There is always danger of children inserting metallic playthings into sockets that may be without lamps and thus cause short circuits which may do harm. Place flush switches so that children can control light

if desired. Avoid receptacles and all opportunities for the use of flexible cord.

The following is a list of devices in general use in many residences and is given as a reminder as to what receptacles may advantageously be provided for in the different rooms.

Only the smaller ones should be connected to electric light circuits.

Broilers
Chafing dishes
Cigar lighters
Coffee percolators
Coil heaters
Corn poppers
Curling iron heaters
Electric fans
Flat irons
Foot warmers
Frying kettles
General utility motor
Griddle cake cooker
Hair dryers
Heating pads
Hardwood floor polisher
Instantaneous water heaters
Massage vibrator
Nursery milk warmers
Ornamental stoves
Ovens
Plate warmers
Ranges
Sewing machine motor
Shaving mugs
Stoves
Toasters
Urns
Vacuum cleaner
Waffle irons
Washing machine motor

SALOONS

In the ordinary saloon not much illumination is required but in the more pretentious a very bright light is often wanted.

It is customary to provide a number of back bar lights scattered above mirrors. These are often so high up that they can be made to answer very well

for general illumination and most of the light may be obtained from them. Globes should be frosted.

Where saloons contain private wine rooms fitted with glass partitions as they often are it is essential to locate the lights in such a manner that shadows of occupants of rooms cannot be thrown against these glass partitions.

In case there are tables along walls these had better be equipped with individual lights.

SHELVING

The proper illumination of shelving is a difficult matter and there is often no way except to provide long pendent cords which will allow of carrying the lamps down to the lowest shelves or in among the goods. Where this method is used there is much annoyance and considerable fire hazard. This can be reduced by the use of reinforced cord. If drops are placed reasonably close together and brought within 6½ feet of floor and each lamp provided with a focusing reflector it will answer nearly all purposes and avoid the use of long cords.

Provide each lamp with strong wire guard. Use 3-way switches liberally.

SHOW WINDOWS.—Small ordinary show windows are best lighted in the manner indicated in Figure 37. No direct rays of light should be visible to the observer and the illumination should be very bright. An extremely bright illumination is called for, more to attract special attention than actually to make the goods visible. Since the main object is to attract attention from other exhibits the best showing is made

if the street is quite dark. If the street is brightly illuminated it will be found that more light is required in the window than with a dark street.

Some show windows are illuminated entirely from the outside but no very brilliant effects can be obtained this way although the light can be made perfectly satisfactory.

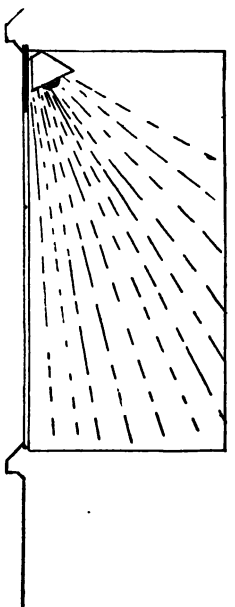

FIGURE 37

In large show windows general illumination is often provided in addition to the reflectors shown in Figure 37. It is not unusual to find 32 c. p. lamps spaced about a foot apart each way on the ceilings of such

show windows. In one case an electric light company is reported as using an illumination of 100 foot candles on floor of window.

Dark spaces caused by shadows of goods and shelving often require special illumination. If necessary lights can be placed along bottom of window to thus light upward into shelves.

There are many places in which the purpose seems to be to show large numbers of electric lights burning rather than to obtain useful illumination therefrom. In such cases the lamps used should be of low candle power and frosted. The disagreeable effect of such an arrangement can also be lessened by the use of lamps made for a higher voltage than that which exists in the installation. This will reduce the brilliancy which is harmful when the source is visible but will also change the colors somewhat.

STREET LIGHTING

Villages.—In villages and suburbs the street lighting is often of a perfunctory nature. Frequently one incandescent lamp is placed at each street intersection. While such illumination is not really noticeable in the middle of blocks still the presence of the lamps is of value in so far that obstructions of a formidable nature between the observer and the next light can easily be seen.

In other instances arc lamps are placed at intersections of streets. Lamps arranged in this manner should always be suspended over centers of street intersections.

Parks.—In parks the object of the illumination is

not merely the narrow drive way or walk but it is desirable that the illumination extend to benches and fields as well. Ponds and lagoons, in Summer for boating, in Winter for skating, require illumination also.

For wide spreading illumination the arc lamps are most suitable and they are also most serviceable at band stands where large crowds gather.

Where the illumination must be brought down below trees or where walks of minor importance are concerned incandescent lamps are more serviceable.

FIGURE 38

Along all curving driveways or walks the lamps should be located as shown in Figure 38. A longer line of lights will be visible and where the illumination is dim an outline of approaching objects can be seen farther off. This arrangement is of less importance where the illumination is quite bright.

Business Streets.—In business streets a very brilliant illumination is often called for. This is especially the case in retail sections where theatres and places of amusement abound or where there is much evening trade. Sometimes this lighting consists entirely of arc lamps, the flaming arcs being especially noticeable but more often where display effects are

sought after incandescent lamps are used. A very common method that has come into use since the advent of the Mazda or tungsten lamps consists in placing clusters of about 4 lamps on ornamental posts spaced according to circumstances and purse of promoters from 20 to 100 feet apart. Lamps on such clusters are always encased in diffusing globes and if placed close enough together a quite even illumination can be obtained.

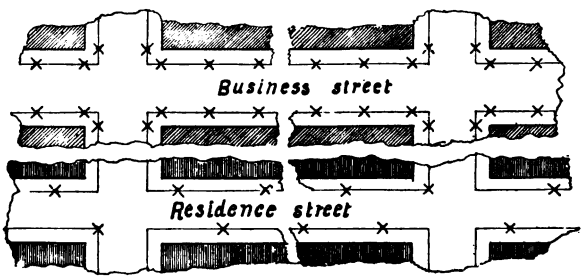

FIGURE 39.

Lamps having the point of maximum intensity from 20 to 40 degrees below the horizontal give good distribution for street lighting. If the point of maximum intensity is too near the horizontal the glare of lamps will be objectionable if they are mounted low enough to give good distribution of light. If too near the vertical the distribution will be very uneven unless lamps are placed very high. Good arrangements of street lighting are shown in Figure 39.

The system to be chosen will depend largely upon conditions and except in the case of an altogether new installation in territory where no electric light wires

exist will have to be arranged to fit in with existing systems.

For series incandescent lighting special lamps are always used. These lamps should be fitted with automatic cutouts so that the burning out of one lamp will not put out the entire series.

On alternating current circuits it must be borne in mind that arc lamps have a very poor power factor.

Not all arc lamps will operate on low frequencies, such as 25 cycles.

Incandescent lamps with thick filaments will not flicker on frequencies as low as 25 cycles but small candle power lamps with thin filaments will.

Always provide lightning arresters for street lighting circuits.

Time switches are very serviceable in many installations of street lighting.

It is customary to use No. 6 wire for all series arc lamp circuits.

The distance apart of poles will be governed largely by the length of blocks which often varies. Ordinarily poles should not be set more than 125 feet apart.

The approximate drop in voltage per mile with various amperes and sizes of wire is given in table below, which is prepared especially for series circuits.

AMPERES

B. & S.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	2	5	7	8	10	13	15	18	20	22	24	26	29	31	33
8	3	7	11	14	18	21	25	28	32	35	39	42	46	49	53
10	6	11	17	22	28	33	39	44	50	55	61	66	72	77	83

The ohmic resistance of the wires considered is so great compared to the induction drop which occurs only in A. C. work that the latter is negligible and the table is fairly correct for frequencies up to and including 60 cycles.

In street lighting the following points should be observed:

Except on business streets where display is of importance no attempt to provide bright illumination should be made. The intensity of moonlight is quite sufficient for all ordinary purposes.

On account of the low intensity which is compelled by reasons of economy it is of special importance that the illumination be as even as possible. Very bright spots contrasted with low illumination make the latter appear dark and unsatisfactory.

At low degrees of illumination it is especially important to use only white light. Flaming arcs and other sources of light of a similar nature should be used only where the flux is quite great.

The use of large units is preferable on account of first cost because it enables us to get along with a minimum number of standards but the quantity of light required is much increased because ordinarily the light is spread equally in all directions and much of it wasted on spaces that are not desired to be illuminated at all. The smaller the unit and the closer placed together the more may the total light be confined to the street which is the object of our illumination.

With incandescent lamps a reflector giving a dis-

tribution in the form of an ellipse can be used but may give the appearance of a head light.

Where large units such as arc lamps are used they should be placed as high as circumstances will permit. The cost of poles and labor of trimming are thereby increased but the effectiveness of the illumination is also increased. Most arc lamps are hung too low, as a rule a height of 35 to 40 feet for high candle power lamps will give the best results. When the distance between lamps is not greater than 300 feet the use of large candle power lamps will give an illumination even enough for street lighting purposes. With larger spacings the results are not good.

Arc lamps should be located at corners so that part of the illumination may be used on cross streets.

Where there are trees it is preferable to use incandescent lamps and locate them below the branches.

Where lamps are spaced long distances apart they should be arranged to project beyond the curb; if placed closely together and staggered this will not be so important.

When lamps are placed low so as to come in the range of vision each globe should be enclosed in some kind of diffusing shade.

No incandescent lamp should ever be installed without suitable reflector.

For satisfactory lighting the lamps should be turned on about 30 minutes after sunset and turned off about 30 minutes before sunrise. This means about 4,000 hours of light per year. The hours of lighting should be based on local and not on standard time.

Often the lamps are burned on a moonlight sched-

ule, that is, the lamps are not lighted on nights when the moon is supposed to be giving sufficient light. Moonlight schedules vary somewhat but ordinarily require the use of the lamps about 2,000 hours per year. The system is not very satisfactory as often nights even near time of full moon are quite dark.

Another method is that of burning the lights regularly until midnight and using a moonlight schedule from then until morning. This means about 3,000 hours of light per year.

The turning off of half of the lights after midnight has also been tried but is seldom found practical.

THEATRES

Front of House.—The front of theatres is often brilliantly illuminated and for this purpose flaming arc lamps are well suited. In addition to this most theatres are equipped with a canopy in front which should be arranged to carry electric signs and is also often provided with a row of lights which serve the double purpose of display and sidewalk illumination under canopy.

For first class theatres it is customary to provide very brilliant illumination so controlled with switches that part of it can be cut out at any time, the full quota of lights being used only during the time that the audience is entering or leaving the theatre.

First class houses are also often equipped with electric signs arranged to serve as carriage calls (See Modern Wiring Diagrams and descriptions for arrangement of circuits) for which provision should be made.

Lobby.—The lobby also is generally equipped with very brilliant illumination controlled by switches so that a large part of it may be cut out except when being used by the public.

The lobby is often highly decorated and there are often valuable works of art placed there which should be properly illuminated (See Art Galleries).

Inverted lighting is quite useful here.

Smoking and Retiring Rooms.—Here home like quiet effects should be sought after. The illumination should be subdued and given a warm color. All glare and garish display should be avoided.

Quaint effects of various kinds are often desirable and there are also often pictures and statuary to be illuminated.

Provide plenty of floor pockets for table lamps, etc.

Auditorium.—In all first class houses a very brilliant illumination is usually striven for but is usually in service only for a few minutes. Often the purpose is as much to show large numbers of incandescent lamps burning as to provide actual illumination and some handsome effects are produced in this way.

Where the decoration is laid out so as to require incandescent lamps to be placed in the line of vision of the audience they should be frosted and should be of small candle power. Such lights should never be depended upon for the actual illumination. They will not be very objectionable during ordinary performances in which they are in use only for a few minutes between acts, but in case of lectures or con-

certs they would be in use continually and become unbearable.

The actual illumination of the auditorium is brought about by means of large chandeliers hung as high as possible to be above the range of gallery; half circles of lamps, sometimes 3 or 4, over main floor; large center domes filled with incandescent lamps; arc lamps or from rows of incandescent lights placed along fronts of balconies and gallery.

If the lighting is to be from fronts of balconies as it is in many houses the main part of it should come from centers as the sides are always visible to parties on opposite side.

Cove lighting along proscenium arch can be worked to good advantage and is especially useful to illuminate decorations.

The illumination under balconies and galleries is a difficult matter.

The ceilings are always low and to obtain even illumination requires the use of many small lamps. These should be placed as high as possible and well back.

There are very few theatres in which these spaces are properly illuminated. The number of sockets provided in different theatres varies greatly. The most lavish illumination at present called to mind consists of 2,500 lamps provided for an auditorium which seats 4,800 people. In less pretentious houses one 16 candle power lamp is provided for each 20 seats. This latter will give a fair illumination and is about the smallest quantity provided in any theatre of standing.

In some theatres a row of lights is arranged around the proscenium arch facing the audience. The object of these lights is to blind the audience for a few moments while a quick change in scenery is being made. The essential conditions of success for this arrangement are: The decorations of the auditorium must not be too light or it will reflect too much of the light back upon the stage. The intrinsic brilliancy of the lamps should be as great as possible for the candle power used (on no account should frosted lamps be used) and the light must be reflected so that none of it can fall directly upon the stage. Emergency lights which are compulsory by law in many places will greatly interfere with this arrangement.

In every auditorium arrangements for lighting for cleaning purposes should be provided. This may be done by arranging for outlets to which stand lamps may be connected or a special circuit which will afford sufficient illumination for this purpose should be run.

Dressing Rooms.—Dressing room illumination if properly carried out will save the proprietor much annoyance. Actors have ways of obtaining the light they want by fair means or foul and it is far preferable to arrange the lighting so it will be satisfactory and answer the purpose than to have it continually tampered with.

In the first place a good bright illumination is essential to make up by and both sides of face should be fully illuminated. For this purpose it is necessary to provide at least 2 lights for each mirror or party.

Actors are very much in the habit of using lamps for drying purposes and for this reason to avoid fire

hazard each lamp should be provided with a wire guard which can be securely locked on. These guards will throw shadows on the faces of occupants and for this reason are very much disliked. These shadows can be pretty well overcome by frosting the lamps or by arranging two small candle power lamps for each side of mirror instead of one large one. The shadows cast by one guard will then be illuminated from the other lamp and be less noticeable.

Where there are long dressing tables as in rooms occupied by the chorus, mirrors may be placed between each two lamps on each side of table and the lights may be staggered vertically. In this way each party will receive the benefit of at least four lamps and thus lessen shadows from guards.

In many theatres where economy is not too much insisted upon it will save much trouble if 32 c.p. lamps are provided for dressing rooms. It is better to provide such lights and control them by door switches for the sake of economy than to force actors to get along with poor light.

It will also be of advantage to see that the color value of the lamps used in dressing rooms is the same as that of the illumination on the stage. Many stages for instance are illuminated with flaming arcs which may give an altogether different effect to make up than, for instance, tungsten lamps.

Orchestra Lights.—A first class theatre should be provided with at least 20 lights for musicians. Theatres built for special purposes such as vaudeville do not require that many and can get along nicely with ten or twelve outlets. Houses devoted to grand opera

on the other hand, often have 100 or more musicians and require a proportionate number of lights. Music stands should be adjustable and so arranged that connections for extra lights may be made from one stand to another and so on.

In most theatres it is necessary to have the music stands equipped with long flexible connections. In case of a purely dramatic show the orchestra can then be crowded under the stage in case of necessity, while for musical shows it will have to be brought out so that the musicians can see the actors and follow their movements. The more the circuits can be subdivided and the more the different lights can be made independent of each other the better it will be and the less will be the annoyance in case a fuse blows. Fuses for orchestra lights should be placed so that they can be replaced without necessitating the operators working in the presence of the audience. Extra stands should also be provided so that it may be unnecessary to repair a broken socket during a performance. An 8 c.p. lamp for each stand will be sufficient. This light is usually placed inside of a special reflector which limits the light to a very small space covering only the music sheet.

It is advisable to place a main switch controlling all of the orchestra lights under control of the musicians so that one of their number may manipulate lights in dark scenes. If lights are placed under control of stage electrician they are more apt to be handled wrong or forgotten.

Stage Switchboard.—All of the lights in the auditorium and on the stage should be under immediate

control of an operator stationed on the stage. It is customary and convenient to place the switchboard by means of which this control is effected at the right hand side of the stage so that the operator may use his right hand to work switches while watching the acts for cues. The right side is also the one from which stage manager prefers to work. In many of the better houses this stage switchboard is now raised sufficiently so as not to interfere with exit passages of the artists.

All good switchboards are divided into two parts each part being fed through one main switch so that the operation of one switch may instantly light up or darken the whole auditorium or stage.

If it is possible to obtain two independent services these should always be installed and connections so made that transfer from one to the other can be instantly made.

In the wiring of the auditorium one of two plans is followed: Sometimes mains are run from the board to different sections of the house and cutout centers are distributed about from which the branch circuits are taken. This method of wiring is undoubtedly the cheapest in first cost but is apt to be very annoying in case fuses blow during a performance.

The best theatres now have the branch wiring all brought to the main board so that any circuit may be refused without delay or disturbance. Each branch circuit should also be provided with a switch and the different sections of the auditorium may be placed under control of main switches so that any desired part of the lighting may be cut out. No mat-

ter how this arrangement is carried out or developed it should always be such that the one main switch will control all of the house lighting that is intended to be used.

In some cities certain emergency lights are required which should be independent of all ordinary switches.

The stage half of the switchboard should be divided into four parts, each part controlled by a main switch, viz: arc light pockets; all white lights including a few stage pockets; all red lights, including at least one stage pocket and all blue lights, also including some stage pockets. At least one stage pocket for each color should be on the same main switch with that color so that all color effects on the stage may be instantly controlled by the operator.

Each color switch will of course have circuits in all foot lights, proscenium side lights and borders.

Each color main switch should lead to a set of bus bars and from these bus bars subswitches are taken to control groups of lamps. For greater convenience these subswitches may be made double throw and an extra set of bus bars provided, the object being to provide the means whereby a part of the lights may be left on while the majority are disconnected by the main switch.

There should be a dimmer for each color, including the white lights and also for each separate location where these lights may be separately used. For instance there should be three dimmers, one for white, red and blue of the foot lights. Similarly, there should be three dimmers for all borders and proscenium side lights on which colors are to be used.

All of these dimmers should be connectable so that they may all be worked together.

The circuits pertaining to the different parts of stage and the switches controlling these circuits should be laid out in the following order, beginning at side nearest center of stage:

Proscenium side lights; foot lights; first border; second border, etc. The dimmers controlling these circuits should be placed directly above the switches which belong to the same circuits.

Aside from accommodating all of the house and stage illumination a good switchboard should also be arranged to control the circuits listed below. It is not necessary that all of these switches be mounted upon the board proper but they should be located convenient thereto so that the electrician in charge can easily superintend them all.

Switchboard lighting circuit. Connected back of main switch.

Dusting circuits.

Fan motor circuits.

Exhaust air motor circuit.

Curtain motor.

Paint bridge motor.

Orchestra lights.

Program lights. In vaudeville houses only.

Paint bridge lights.

Fly floor lights.

Rigging loft lights.

Stage chandelier circuit.

Arc circuits on bridge.

Arc circuits at stage level.

Plugging box circuit. Usually only a switch and fuses to which main cable feeding plugging boxes can be attached.

Electric sign circuit.

In most of the larger cities it is insisted upon that the lobby and exit lights, often also a certain number of emergency lights be fed from a separate circuit and controlled only in front of house. The illumination for front of house can also be best controlled from there.

Foot Lights.—The foot lights are arranged slightly below the level of the stage so as not to obstruct the view of the stage by those in the pit near the orchestra. They usually extend clear across the full stage opening and it will be well to provide as many lights as can be crowded into this space. In single rows the lights are spaced about 3 inch centres.

Provision should be made for three colors but the white will predominate, it being customary to have half of the lights white and divide the remainder equally among the other colors. It will also be well to arrange the circuits so that a small part of the white lights can be used for rehearsals or to illuminate a particular section of the stage. The proper placing of foot lights requires very careful study. If placed too high they obstruct the view of those nearest them in the audience. If too low they will not properly illuminate the lower part of actors. Where foot lights are placed in two rows the white lights should always be placed in the front row.

Proscenium Side Lights.—These are not provided in all theatres and in most of those where they are

found they are of very little use. If they are to be of any use they must be set well forward of the curtain line so as to permit of the light being thrown well toward the center of the stage. In houses devoted to musical shows and large choruses that spread over the entire stage these lights are of more use than in dramatic houses where the interest is more confined to the center of the stage. In very well equipped theatres these side lights are also provided with three color circuits but in ordinary houses only a single circuit is run on each side of stage. So-called "Baby Spots" are often used as proscenium side lights. Lamps may also be placed as close together as 3 inch centers.

Borders.—All borders must be made adjustable as to height. It is necessary at times to raise them way above scenery and they must be lowered to the stage for lamping up and cleaning.

The cables over which lights are fed should be fastened high up and in the center of borders.

The number of borders provided varies from one to six. Only the very largest theatres are provided with six borders but four are quite common.

Some of the smaller theatres manage to get along with one border. Each border should carry circuits for three colors just as the foot lights do. Not as much illumination is ordinarily required from borders as from foot lights and lamps are often placed for 6 to 12 inch centers.

Stage Pockets.—Stage pockets are provided to supply current to special electrical effects such as arc lamps, portable strips, motors, bunch lights, etc. Whatever coloring is produced by arc lamps is sup-

plied by operators and slides held in front of lamps. It is therefore not necessary to arrange arc circuits on the same main switches with any of the color incandescent lights, but very convenient to have some of them so arranged.

Colored strips and bunch lights are, however, often used in conjunction with colors in foot lights and borders and incandescent circuits should therefore be connected to the same main switches that control those colors, that is at least one incandescent pocket on each side of stage should be grouped with each color on borders or foot lights.

Stage pockets are always located at sides of stage and distributed from front to rear so that a minimum of cable will be required to connect from pocket to lamps. Each pocket usually contains four circuits. The average stage in first class houses will have 3 or 4 pockets on each side of stage but if more can be provided it will be a great convenience. There are exhibitions which use from 30 to 40 arc lamps.

In lieu of a large number of stage pockets a special circuit for plugging box mains may be provided. Plugging boxes will then take the place of the pockets.

One such circuit should always be provided as many shows carry special switch boards or dimmers connected to suit their particular requirements and which must be provided with main wire connections.

Bridges.—In many theatres stage pockets are located on so called bridges or galleries located from 10 to 20 feet above stage level. Stage chandelier circuits are best run from such locations.

Fly Floor.—Fly floor is the term given to the gal-

lery on which that part of the scene shifters whose duty it is to raise and lower scenery and curtain work. Not a great deal of illumination is actually needed here but much annoyance will be avoided if a few lights are placed for the convenience of men to read by during the acts. All lights on fly floor should be controlled by three way switches so they may be turned on or off at floor or at stage switch board.

Stage Lighting.—The cheapest illumination of acts and features on the stage, where foot light illumination is not deemed sufficient, is obtained by one or more spot lights placed in balcony or gallery, the light being thrown directly upon the act. If a stronger illumination is required it is necessary to place arc lights on both sides of stage. This is the proper way to illuminate a dancer, for instance, and very often two spot lights are placed in the wings as far to the front as possible. These lights are each controlled by an operator who must train his lamp so that it will follow all of the dancer's movements. This illumination is often helped out by additional lamps placed on bridges and in front, and to still further enhance the effect of the illumination the stage is draped in dark colored fabrics which are not illuminated. Extremely brilliant effects are often sought after.

For the illumination of back drops, scenery, etc., open arc lamps are generally employed and in some cases from 20 to 30 are in use at the same time.

Bunch lights and portable strips are also often distributed about the scenery to obtain certain effects.

Arc lights can of course not be arranged on dimmers; they are often controlled by shutters which mo-

mentarily shut out the light. Color effects with arc lamps are obtained by inserting colored gelatines in front of the lamps.

All of the foot lights, borders, proscenium lights, etc., are connected so they come under control of dimmers and for color effects colored incandescent lamps are always used. Such lamps are generally colored as needed.

As the eye judges distance by the space between lamps where there are no other objects to mark distance the illusion of a long distance may be obtained by a row of lights diminishing in distance from lamp to lamp or in intensity or both. The same effect can be obtained by the use of lines converging toward an artificial vanishing point. This is often emphasized by a high intensity of light in the foreground and a much lower intensity in the background.

Lightning.—A lightning effect may be obtained by momentarily establishing a circuit through a piece of carbon which is being rubbed over a file. Sometimes the effect is produced by flashing one or more of the borders for an instant.

The standard method of producing lightning, however, consists in a mechanical device in which a piece of carbon is caused to make contact with another for a very short time. Sometimes an electro-magnet is provided which opens the circuit the instant it has been made and at other times the circuit is broken mechanically.

The effect of lightning striking a certain spot is often produced by a piece of metal sliding swiftly down a piece of wire, the wire being one pole of the

circuit and the metal connected by special wire as the other. In sliding down the contact is made and broken a number of times and thus the effect of a lightning stroke is produced. The same effect can be produced more safely by enclosing suitable carbons electrically connected in a small gauze enclosure and arranging this to slide down a wire. The jarring will cause the circuit to be made and broken a number of times, and the arc will always be enclosed.

A rising sun effect may be produced by suitable colored strips and borders under control of dimmers and worked in proper order. In some cases the effect is produced by slowly raising arc lamps behind a colored screen, the colors of which are deep red at the bottom and gradually fading to light toward the top.

For living picture exhibitions a special frame is generally provided. This frame carries lamps of whatever colors may be desirable so arranged as to be shielded from the audience while illuminating the figures.

Ghost like effects and acts sometimes depend entirely upon a few bright lights placed directly in front of the audience and provided with shades so that actors can work behind them without being seen. The illumination may be such that only bright figures can be seen behind the lights.

TRAIN LIGHTING

The standard voltages used for train lighting range from 28-34 and 57-65.

One of the main peculiarities that must never be

lost sight of is the fluctuation in voltage which is greater in this kind of lighting perhaps than in any other. Most of the train lighting is supplied from dynamos located in one of the cars nearest the engine from which steam is taken. A storage battery is also often used in conjunction with the dynamo.

On some roads dynamos are coupled to the car axles and driven by them.

It is very desirable that high efficiency lamps be used not only on account of the saving in energy but also in the saving of space occupied by generating equipment as well as the weight thereof. It is not customary to provide very brilliant illumination except in the most elaborate Pullman cars. There should be a 16 c.p. lamp for each seat in ordinary cars.

TRAIN SHEDS

In train sheds the arc lamp is still much in favor and is perhaps the best means of illumination, though tungsten clusters may be freely used. Whatever method of illumination is used the lamps will require frequent cleaning and this fact gives some advantage to arc lamps since they are naturally cleaned every time lamps are trimmed. Fine lighting can be obtained by placing enclosed arc lamps in rows between tracks about 30 feet apart.

TAILORING

Cloth Cutting Rooms.—The illumination in these places must be general and fairly even as the tables often extend over full length of room.

The best illumination is either by arc lamps, clus-

ters of incandescent or large tungsten units. The lights should be placed as high as obstructions under ceilings will permit.

Provisions should be made for cloth cutting motors. Each of these will require a separate circuit.

Sewing Rooms.—It is customary to provide an incandescent lamp for each sewing machine or tailor, and these are usually supported by pendant cord and brought down close to workmen's eyes.

Much better results can, however, be obtained by providing good general illumination hung sufficiently high to avoid the glare which always goes with a single source of light. Workmen engaged in this kind of work are mostly arranged at long tables so that all lights may be placed in straight rows. The general illumination need therefore be along the length of this row only and by means of reflectors should be confined so as not to spread where not needed.

In whatever way the illumination may be provided it should be somewhat adjustable. Circuits should be left lightly loaded so that lamps of greater candle power may be given to those with very trying work or poor eye sight. It is wasteful of electrical energy as well as productive of much unnecessary eye strain to compel all employes to work by the same illumination regardless of the nature of the goods in hand.

If circuits are properly laid out it will always be possible to drop an extra lamp of small candle power where it is actually needed.

In connection with sewing machines it will per-

haps often be necessary to provide a pendant adjustable lamp for each machine. But if there is a good general illumination this lamp may be of low candle power and the effect much improved.

The method recommended will add to the cost of installation but not to the cost of operation. Owing to the rough handling that pendant lamps receive in such places it is not advisable to use high efficiency lamps on pendant cords whereas such lamps can be used with perfect freedom in rigid construction out of control of workmen. Inverted lighting would be very useful about sewing machines.

If electric irons are to be installed they should each be provided with a separate circuit.

Arc lamps have formerly been used extensively in sewing rooms but cannot compare at present with tungsten lamps properly installed.

CHAPTER XV

TABLE OF INTENSITIES IN FOOT CANDLES RECOMMENDED FOR VARIOUS CLASSES OF SERVICE

In connection with this table a few words of explanation are necessary. The recommendations are in the main an outline of the intensities in general use but it must not be understood that the intensities given are provided evenly throughout the spaces considered. It would be practically impossible to provide an even illumination as low as 0.5 foot candles except by the use of very small units or by mounting lamps extraordinarily high, both of which methods would of course be very wasteful.

The purpose of the tables is not to give the intensity actually used but the quantity of light used in different places. It will be noted that there is always a considerable range between the minimum and maximum used in the various localities. This may be understood by some to destroy the value of the recommendations but this is erroneous. Illumination is not provided only for the purpose of making objects visible. It is provided also as an advertising medium and very often the degree of illumination is adjusted to the class of customers. Stores which deal largely with the poorer classes, for instance, do not provide

as brilliant an illumination as those which cater to the wealthy.

It has been pointed out before that there are two methods of calculating illumination in general use, viz: the Flux of Light and the Point by Point methods.

For low intensities the flux of light method is the only one that can be used. The formula which is used is

$$\frac{\text{Area times Intensity}}{\text{Lumens effective per lamp}} = \text{Lamps}$$

area being expressed in square feet; intensity in foot candles and lumens effective varying with the kind and size of lamp used and reflecting power of walls, etc. By the use of this formula we can determine the number of lamps of a given size required to give an average intensity such as recommended in the table. But the average illumination may not be an even illumination. If we care anything about the degree of variation we shall be obliged to check up by the point by point method or some other. A study of the various illumination tables will be of assistance.

Before laying out the plan of illumination it will be well to consult chapter entitled "Practical Considerations" as to the best means and arrangement of lamps.

The following table shows the approximate number of watts required for the illumination of one square foot to an intensity of one foot candle with incandescent lamps of various kinds used at top voltage. The figures represent an average of various recommendations and should be used only in places where

lamps are not more than 15 feet above plane illuminated and where they are fitted with prismatic glass reflectors. If fitted with a good grade of white glass reflectors or satin finished prismatic glass the watts per square foot will be slightly increased but the softening effect of the light will generally fully offset the small decrease in intensity or increase in current consumption.

Type of lamp	Color of ceiling	Color of walls	Watts per square foot per foot candle
Tungsten	Light	Light	0.20
Tungsten	Light	Dark	0.25
Tungsten	Dark	Dark	0.30
Tantalum	Light	Light	0.33
Tantalum	Light	Dark	0.40
Tantalum	Dark	Dark	0.50
Gem	Light	Light	0.45
Gem	Light	Dark	0.55
Gem	Dark	Dark	0.65
Carbon	Light	Light	0.55
Carbon	Light	Dark	0.65
Carbon	Dark	Dark	0.75

Where the recommendations give high intensities there will be less difficulty in this respect.

Location	Foot candles
Armories or drill halls	2 to 5
Art Galleries:	
White statuary	2 to 3
Bronze statuary	6 to 8
Paintings on walls	4 to 6

Assembly rooms	2 to 5
Auditoriums	1 to 3
Ball rooms	2 to 4
Banks, general	.5 to 3.5
Barber shops	2 to 3
Bed rooms	1.5 to 2
Billiard rooms; general	0.75 to 1
Billiard tables	4 to 5
Blacksmith shops	2 to 3
Bowling alleys; general	1.5 to 2
Bowling alleys; at pins	3 to 4
Bookkeepers desk	3 to 5
Cigar stores	2.5 to 3.5
Composing rooms	6 to 10
Churches, general	2 to 3
Corridors and halls	0.5 to 1
Courts, hand ball, etc.	6 to 8
Court rooms	2 to 3
Clothing stores	4 to 7
Desks	3 to 4
Depot waiting room	1.5 to 2
Dining rooms	1.5 to 2
Drafting rooms	6 to 10
Drug stores	3 to 5
Dry goods, light goods	3 to 6
Dry goods, dark goods	4 to 8
Engraving rooms	5 to 10
Factories, with local lights	1.5 to 2
Factories, no local lights	3 to 4
Foundries	2.5 to 3.5
Furniture stores	4 to 5
Garages	1.5 to 2.5

Grocery stores	2.0 to 3.5
Gymnasiums	2 to 3
Hardware stores	4 to 5
Hospital wards, general	1.5 to 2
Hospital wards, with local	0.5 to 1
Hospital operating rooms	10 to 15
Jewelry stores	4 to 5
Kitchens	1.5 to 2
Laboratories	3 to 4.5
Laundries	2 to 2.5
Libraries, general	1.5 to 2
Libraries, at reading tables	3 to 4
Lodge rooms	2 to 3
Machine shops, average work	3
Machine shops, fine work	6
Meat markets	3 to 4
Men's furn. stores	3 to 4
Millinery stores	3 to 5
Music stores	3 to 4
Merchant tailors	3 to 5
Offices:	
General, with local lights	1.5 to 2
No local lights	3 to 4
Parlors	1.5 to 2.5
Photo gallery	4 to 5
Pool rooms, general	0.75 to 1
Pool tables	4 to 5
Post offices	2 to 5
Press rooms	3 to 5
Reading rooms	2 to 3
Residences, general	1 to 2
Restaurants	2 to 2.5

Saloons	2 to 4
School rooms	2 to 3
Sewing rooms	4 to 8

SHOW WINDOWS

Light goods	6 to 8
Medium goods	10 to 15
Dark goods	15 to 20
Shipping rooms	1.5 to 2
Shoe stores	3 to 4
Stables	1
Stationery stores	3 to 4
Storage rooms	0.5 to 1
Train sheds	1 to 1.5
Warehouses	1 to 1.5
Yards	0.5 to 1

CHAPTER XVI

PLANS AND SPECIFICATIONS

In Figure 40 is given a section of a floor plan of a modern office building. The symbols used in this plan are those recommended by the National Electrical Contractors' Association and it would be well if these were more generally adopted than they are at present. If symbols other than these are used their meaning should be made clear and noted on plans.

The plan shown is worked out very well in detail and shows the precise manner in which circuits are to be run as well as the size of conduit, location of switches and position of cutout center. If such plans are provided and rigidly followed much time and labor may in the future be saved if it becomes necessary to make alterations. And it may be stated that in connection with office buildings alterations are continually in progress. One of the chief requisites of the wiring of an office building is, that it must have sufficient capacity to allow of large additions.

For residences and smaller buildings it is not customary to lay out the wiring on plans in detail and the manner of distribution of circuits is often left to the men that do the work. Where the work is im-

portant and especially where certain switching arrangements are desired it is well to make detail plans to avoid misunderstandings.

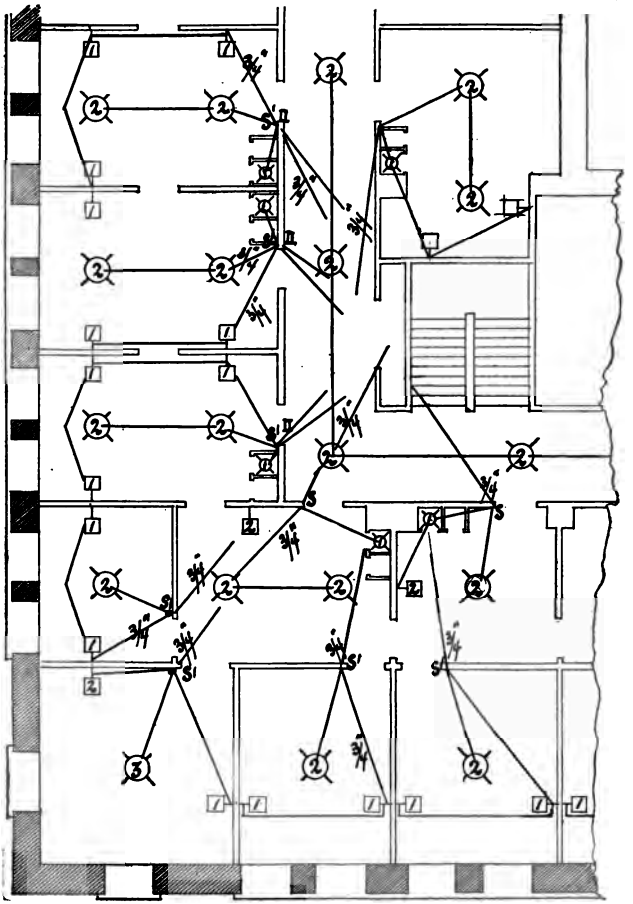

FIGURE 40

In all cases before laying out plans and specifications the recommendations given in Chapter "Practical Considerations" under the proper headings should be consulted.

If standard plans are not available a rough pencil sketch may be made to answer the purpose.

Before preparing plans or specifications or determining the general character of the installation all of the points covered in the following memorandum should be learned and considered.

MEMORANDUM ON WHICH TO BASE PLANS AND SPECIFICATIONS

Pencil sketch or plans of room or rooms.
Dimensions of each room.
Location of doors and windows in each room.
Location of furniture.
Location of glass partitions.
Height of ceilings.
Color of ceilings.
Color of walls.
Nature of decorations or of pictures on walls.
Occupation of users of light in each room.
Is minimum amount of light wanted?
Is a comfortable light wanted?
Is a strong display light wanted?
How many hours per day is light used?
How long is it likely that installation will remain?
Is economy in first cost or general economy of maintenance and operation the main consideration?

The above information being at hand one can readily determine the most suitable method of illumination and proceed to draw up the specifications.

The specifications should begin by setting forth the general scope and purpose of the work; location of building, business, and other preliminary items that may be necessary to a clear understanding of the premises by all parties and may further mention the following points.

Time of starting work.

Time when work is to be finished.

Days or portions of days when no work will be allowed by owner.

Work on holidays; overtime.

Additional work that may come up not provided for in contract.

Forfeiture Clause. This clause if inserted is apt to do more harm than good. The contractor is likely to charge in his bid for the chances he must take on account of circumstances often beyond his control. And if such circumstances occur he is very likely to beg off. As the forfeiture is seldom enforced, it is likely to cost the owner more than the benefit he derives from it is worth. If it is inserted at all it should be with the definite understanding that it will be rigidly enforced.

Guarantee to Keep in Repair. This is also an item for which the contractor will charge and should be mentioned only if the contract is to be let only to thoroughly reliable people. This of course does not apply to maintenance companies or special devices, but only to the general installation.

Inspection and Inspection Certificate.—To provide for proper inspection and the use of "National Electrical Code" materials is the best safeguard for sub-

stantial work and should make guarantees unnecessary. Every reliable contractor welcomes fair inspection because without it the whole contracting business would be simply a race as to who could do the poorest and cheapest work. A contractor who belittles good inspection gives evidence of insincerity.

Workmanship.—Good workmanship should always be insisted upon. The small saving made by allowing cheap incompetent mechanics to install the work is soon forgotten, while the botch work remains always in sight. "Quality is remebered when price is forgotten" is a good motto. The contractor should by all means assume all repairs to plaster and other parts of finished buildings. If this is not the case often to save a few cents in labor reckless damage may be done that will cost the owner as many dollars to repair.

Time of payments.

Class of construction.

System of supply.

Rules of company furnishing current.

It is important that these be understood at the beginning by all parties.

Location and description of mains and submains: 2 or 3 wire.

Description of switchboard.

Description of panel boards and cut-out cabinets.

Number and location of distribution centers.

Location of meters.

Description of wires.

Largest size solid wire to be permitted.

Description of material.

In all specifications it should be provided that only "National Electrical Code" materials be used.

Maximum full load loss on mains between service entrance or dynamo and center of distribution. This should not exceed 1%.

Maximum full load loss on branch circuits. Should not exceed 1%.

Greatest length of circuit for which No. 14 wire may be used. See tables No. XVII and XVIII. This is governed by the loss in voltage to be allowed.

Number of lights per circuit. Never more than 12.

Sizes of conduit and number of wires in any one conduit. See N. E. code.

Location and height of switches.

Location and height of brackets.

Location and capacity of ceiling outlets.

Location and capacity of special outlets.

Drop cords to be furnished by.

Fixtures to be furnished by.

Fixtures to be hung by.

Schedules of mains and submains.

Schedule of outlets, switches, location, etc.

In the awarding of contracts one should guard against those who advise a cheap installation or who recommend the lowest degree of illumination. Many unscrupulous solicitors mislead their customers by advising a low degree of illumination for the double purpose of thus getting in the lowest bid and later, when the lighting proves unsatisfactory, of getting high prices for extra work. Also guard against specifying special materials not carried by dealers generally unless there are good reasons for doing so.

The following memoranda will be of use in taking orders or estimating cost of rough wiring or fixture work. Lack of space forbids carrying these out as far as desirable. They can, however, easily be enlarged by users.

MEMORANDUM OF ROUGH WIRING

Name.....
Address.....
Pencil sketch showing dimensions, number of floors, etc. .....
Total number of lights and watts.....
System of supply.....
Voltage .....
Length of mains; one leg.....
Full load loss on mains.....
Number and location of distributing centers.....
Number of branch circuits.....
Loss in branch circuits.....
Location of service switch.....
Location of meters.....
Number s.p. switch outlets.....
Location of switch outlets.....
Number d.p. switch outlets.....
Location of switch outlets.....
Number 3-way switches.....
Location of switches.....
Number 4-way switches.....
Location of switches.....
Number bracket outlets.....
Height above floor.....
Number ceiling outlets.....

Number fan motor receptacles.....
Number special receptacles; one per circuit.....
Percentage or number feet conduit.....
Percentage or number feet fish work.....
Percentage or number feet wood moulding.....
Percentage or number feet metal moulding.....
Percentage or number feet open wiring.....
Percentage or number feet knob and tube work.....
Conditions governing time at which work may or may not be done.....

Memorandum of Fixture Work

Name..... Address.....	Room or Circuit Number						
Chandeliers							
No. lights on each circuit							
No. of beam lights							
No. of electric lights							
No. of gas lights							
Style of finish							
Catalogue number							
Sketch number							
Kind of glass ware							
Catalogue number							
Size of holders							
Kind of sockets							
Height lowest point above floor							
Size of gas stub							
Brackets							
No. of elec. lights							
Kind of sockets							
No. gas lights							
Style of finish							
Catalogue number							
Sketch number							
Kind of glass ware							
Catalogue number							
Height above floor							
Size gas stub							
No. switches							
Kind of switch							
Style of finish							

Always check up and see that no circuit is overloaded.

In case of large space number each circuit.

CHAPTER XVII

ILLUMINATION TABLES

The point by point method of calculating illumination is quite laborious and intricate and to reduce the trouble and labor involved as much as possible the following tables have been prepared.

Table V will be found useful in calculating the illumination obtainable from a single unit such as may be used for the illumination of an office, lobby, sitting room or similar space where it is desirable to know the intensity under the lamp, on walls or on a plane normal to the rays of light.

The values given in line "Normal" naturally would be those used for reading, since one would ordinarily hold the book or paper at right angles to the rays to obtain the best light.

The vertical illumination is that which would fall upon walls and be used for the illumination of pictures and decorations.

The horizontal illumination would be used on desks, etc., for writing and also often for reading.

To find the foot candles at any distance from point directly beneath center of lamp and at any height of suspension, read photometric curve at corresponding angle and multiply the candle power found by deci-

Table V

Table Showing Intensity of Illumination in Foot Candles on Horizontal, Vertical and Normal Planes at Distances Given in Table. Light Source of One Candle Power

Height of light source in feet above point illuminated		Horizontal Distance in Feet from Point Directly Beneath Lamp to Point Considered.												
		0	1	2	3	4	5	6	7	8	9	10	11	12
4	Degrees	0° 0′	14° 2′	26° 34′	36° 52′	45° 0′	51° 20′	56° 19′	60° 15′	63° 26′	66° 2′	68° 12′	70° 1′	71° 34′
	Horizontal	.06250	.05707	.04472	.03200	.02210	.01524	.01066	.00764	.00559	.00419	.00320	.00249	.00198
	Vertical		.01424	.0224	.02401	.02209	.01903	.01600	.01336	.01117	.00941	.00800	.00686	.00729
	Normal	.06250	.05882	.05000	.04000	.03125	.02439	.01923	.01538	.01250	.01030	.00862	.00593	.00625
5	Degrees	0° 0′	11° 19′	21° 48′	30° 58′	38° 40′	45° 0′	50° 11′	54° 28′	58° 0′	60° 57′	63° 26′	65° 34′	67° 28′
	Horizontal	.0400	.03771	.03202	.02522	.01904	.01414	.01050	.00785	.00595	.00458	.00358	.00283	.00228
	Vertical		.00753	.01280	.01575	.01524	.01414	.01259	.01100	.00952	.00825	.00715	.00624	.00546
	Normal	.0400	.03846	.03448	.02941	.02439	.02000	.01639	.01351	.01123	.00942	.00800	.00685	.00591
6	Degrees	0° 0′	9° 28′	18° 26′	26° 34′	33° 42′	39° 48′	45° 0′	49° 24′	53° 8′	56° 19′	59° 3′	61° 23′	63° 26′
	Horizontal	.02778	.02673	.02372	.01987	.01600	.01260	.00982	.00766	.00600	.00474	.00378	.00305	.00249
	Vertical		.00446	.00789	.00995	.01067	.01049	.00982	.00893	.00799	.00711	.00630	.00558	.00497
	Normal	.02778	.02700	.02500	.02222	.01923	.01639	.01388	.01176	.01000	.00854	.00735	.00637	.00555
7	Degrees	0° 0′	8° 8′	15° 57′	23° 12′	29° 45′	35° 32′	40° 37′	45° 0′	48° 49′	52° 7′	55° 1′	57° 31′	59° 45′
	Horizontal	.02041	.01980	.01814	.01585	.01336	.01100	.00893	.00722	.00583	.00473	.00385	.00316	.00261
	Vertical		.00281	.00520	.00679	.00714	.00784	.00765	.00721	.00676	.00607	.00549	.00500	.00447
	Normal	.02041	.0200	.01887	.01724	.01538	.01351	.01176	.01020	.00885	.00769	.00671	.00588	.00518
8	Degrees	0° 0′	7° 8′	14° 2′	20° 33′	26° 34′	32° 0′	36° 52′	41° 10′	45° 0′	48° 22′	51° 20′	53° 59′	56° 19′
	Horizontal	.01563	.01527	.01427	.01283	.01118	.00953	.00800	.00667	.00552	.00458	.00381	.00318	.00267
	Vertical		.00190	.00355	.00481	.00559	.00585	.00600	.00594	.00552	.00515	.00475	.00437	.00401
	Normal	.01563	.01538	.01470	.01369	.01250	.01123	.01000	.00885	.00781	.00689	.00609	.00540	.00481
9	Degrees	0° 0′	6° 20′	12° 32′	18° 26′	23° 55′	29° 3′	33° 42′	37° 52′	41° 38′	45° 0′	48° 0′	50° 42′	53° 8′
	Horizontal	.01235	.01212	.01148	.01054	.00943	.00825	.00711	.00607	.00515	.00437	.00370	.00314	.00267
	Vertical		.00136	.00254	.00350	.00417	.00457	.00474	.00472	.00457	.00436	.00410	.00388	.00355
	Normal	.01235	.01219	.001176	.01111	.01031	.00943	.00854	.00769	.00689	.00617	.00552	.00495	.00444
10	Degrees	0° 0′	5° 43′	11° 19′	16° 42′	21° 48′	26° 34′	30° 58′	35° 0′	38° 40′	41° 59′	45° 0′	47° 43′	50° 11′
	Horizontal	.01000	.00985	.00943	.00879	.00801	.00716	.00631	.00550	.00476	.00411	.00354	.00304	.00268
	Vertical		.00098	.00188	.00263	.00320	.00358	.00378	.00384	.00381	.00369	.00353	.00334	.00315
	Normal	.01000	.00990	.00961	.00918	.00862	00800	.00735	.00671	.00609	.00552	.00500	.00452	.00409

mal number set under this angle where lines pertaining to height and distance cross. The result will be the intensity in foot candles on horizontal, vertical, or normal plane according to which one we choose to multiply with.

Example: Find the foot candles on horizontal plane 7 feet below and 10 feet from lamp. Referring to table we find that we must read our curve at 55 degrees and multiply by .00385. If our curve shows us at this point 60 candle power, we have 60 times .00385 equals .231 foot candles.

If the lamp does not hang vertically but is placed at an angle, the photometric curve should be placed at the same angle and the point directly beneath it assumed to be 0 degrees.

In sewing rooms, on work benches, inspection benches, etc., it is often necessary to obtain very good even illumination from one or more rows of lamps. Tables VI to XI are provided to obviate the necessity of entering into lengthy calculations. These tables give in direct reading the intensity in foot candles existing at different heights of units above plane to be illuminated and at different distances apart. It is assumed that, where more than one row is considered, lamps are placed in squares as indicated in Figure 41. All of the tables are calculated from values given in Bulletin 7B compiled by the Engineering Department of the National Electric Lamp Association. These tables are also all based upon the use of Holophane reflectors as noted with each table and where it is not desired to use these reflectors other reflectors the "curves" of which approximate to

those of the above should be used. Such reflectors are standard and it is not likely that any very serious errors will be introduced if reasonable care is used in selecting them.

In the foot candle values given, no reflected light has been taken into consideration, in most cases there will, therefore, be an increase in illumination over the values given in the tables. Where large surfaces are considered this reflected light will not affect the center of the spaces much. In small places it may add from 50 to 100 per cent if walls are light and clean. In general the effect of reflection will be to bring the outer illumination fully up to if not above that of the center.

The method of using the tables is very simple and may readily be explained by an example. Suppose it is desired to provide an illuminant of from 2.5 to 3.0 foot candles on a certain work bench; one row of lamps to be used. Considering 25 watt lamps (table for one row), 4 feet above bench and spaced 5 feet apart, we shall be able to obtain 2.7 foot candles under lamps and 2.4 between. By the use of 40 watt lamps spaced 6 feet apart and 5 feet above bench we shall be able to obtain 2.7 foot candles both under and between lamps. By the use of 60 watt lamps spaced 8 feet apart and 6 feet above table, we should obtain 2.9 foot candles under, and 2.6 between lamps. Thus it can be seen that by use of the tables the best illumination for any ordinary conditions can be readily selected without resorting to any calculations.

Figure 41 will illustrate the points referred to by the terms "Under lamps" and "Between lamps" in

the tables. The black circles designate the points at which the illumination given in column "Under lamps" is figured and the small crosses the points at which "Between lamps" is figured.

The rows are figured to contain at least 9 lamps, where candle power and distances are small; if there are not that many the illumination will not be quite equal to that given in the tables.

An inspection of tables for 4 rows will show that the increase over 3 rows is but slight, and it is therefore not necessary to carry the calculations any far-

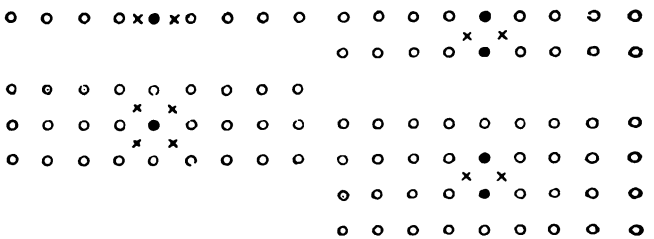

FIGURE 41

ther. The four row table can be safely used for all large spaces, where lights are arranged in that many or more rows. It can be also seen from the tables that the law of inverse squares does not apply when there are a large number of lamps placed so close together that the space under each lamp is also illuminated by a large number of surrounding lamps. Examine, for instance, the table for four rows. With 25 watt lamps spaced 3 feet apart each way we have 9.2 foot candles 4 feet below the lamp. At a distance of 12 feet below the lamp the illumination has

TABLE VI

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 25, 40 AND 60 WATT MAZDA OR TUNGSTEN LAMPS ARRANGED IN ONE ROW AT HEIGHTS AND DISTANCES APART GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS, NOS. 106,125, 106,130 AND 106,150 RESPECTIVELY.

DISTANCE APART OF LAMPS

Height of lamps in feet above plane to be illuminated.	Wattage	3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps
4	25	4.22	4.16	3.13	3.2	2.7	2.4	2.4	1.9	2.2	1.5	2.1	1.1	2.0	0.6	2.0	0.4
	40	7.31	6.43	5.53	5.0	4.7	3.9	4.3	3.1	4.1	2.3	3.9	1.6	3.8	0.9	3.8	0.5
	60	11.22	10.83	8.24	8.2	7.0	6.5	6.3	5.1	5.9	3.8	5.7	2.6	5.6	1.5	5.5	0.8
5	25	3.3	3.3	2.5	2.5	2.0	2.0	1.8	1.6	1.6	1.3	1.5	1.1	1.4	0.7	1.3	0.4
	40	5.2	5.2	4.0	3.9	3.1	3.2	2.7	2.7	2.4	2.2	2.3	1.8	2.1	1.0	2.1	0.6
	60	8.9	8.7	6.7	6.6	5.3	5.4	4.6	4.4	4.2	3.6	3.9	2.8	3.7	1.6	3.6	1.0
6	25	2.7	2.7	2.1	2.1	1.7	1.7	1.4	1.4	1.2	1.2	1.1	1.0	1.0	0.7	0.9	0.5
	40	4.3	4.2	3.2	3.2	2.7	2.6	2.2	2.2	1.9	1.8	1.7	1.5	1.5	1.1	1.5	0.7
	60	7.2	7.1	5.5	5.3	4.4	4.4	3.6	3.7	3.2	3.1	2.9	2.6	2.6	1.8	2.5	1.1
7	25	2.3	2.3	1.8	1.8	1.4	1.4	1.2	1.2	1.0	1.0	0.9	0.9	0.8	0.6	0.7	0.5
	40	3.6	3.6	2.8	2.7	2.2	2.2	1.9	1.8	1.6	1.6	1.4	1.4	1.2	1.0	1.1	0.8
	60	6.1	6.0	4.7	4.7	3.8	3.7	3.1	3.1	2.7	2.7	2.4	2.3	2.1	1.7	2.0	1.2
8	25	2.0	2.0	1.6	1.5	1.2	1.3	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.4
	40	3.1	3.1	2.4	2.4	1.9	2.0	1.6	1.6	1.4	1.4	1.2	1.2	1.0	0.9	0.9	0.7
	60	5.3	5.3	4.1	4.1	3.3	3.3	2.8	2.7	2.4	2.3	2.1	2.1	1.7	1.6	1.6	1.2
10	25	1.5	1.5	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4
	40	2.5	2.4	2.1	1.9	1.6	1.6	1.3	1.3	1.1	1.1	1.0	1.0	0.8	0.8	0.7	0.6
	60	4.2	4.0	3.2	3.2	2.6	2.6	2.2	2.2	1.9	1.9	1.6	1.6	1.3	1.3	1.1	1.1
12	25	1.2	1.2	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4
	40	1.9	1.9	1.6	1.5	1.3	1.3	1.1	1.1	0.9	0.9	0.8	0.8	0.6	0.6	0.5	0.5
	60	3.3	3.2	2.6	2.5	2.1	2.1	1.8	1.8	1.6	1.5	1.3	1.4	1.1	1.1	0.9	0.9

TABLE VII

Table Showing Illumination in Foot Candles from 25, 40 and 60 Watt Mazda or Tungsten Lamps Arranged in Two Rows at Heights and Distances Apart as Given in Table. Bowl Frosted Lamps Equipped with Holophane Intensive Clear High Efficiency Reflectors Nos. 106,125, 106,130 and 106,150, Respectively.

Distance Apart of Lamps Each Way

Height of lamps in feet above plane illuminated.	Wattage	3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps
4	25	6.4	6.9	4.3	4.1	3.3	3.1	2.7	2.2	2.4	1.3	2.3	1.0	2.1	0.5	2.0	0.2
	40	10.8	11.0	7.2	6.9	5.6	4.9	4.8	3.4	4.4	1.9	4.3	1.5	3.9	0.6	3.8	0.4
	60	16.8	18.3	10.8	10.8	8.3	7.9	7.0	5.3	6.4	3.0	6.0	2.3	5.8	1.0	5.6	0.6
5	25	5.5	5.8	3.8	3.7	2.7	2.9	2.2	2.3	1.9	1.5	1.7	1.2	1.5	0.6	1.4	0.4
	40	8.8	9.1	5.9	5.9	4.2	4.7	3.3	3.7	2.8	2.2	2.8	1.7	2.2	0.8	2.1	0.5
	60	14.6	15.1	9.8	9.8	6.9	7.6	5.5	5.8	4.7	3.4	4.3	2.7	3.8	1.3	3.7	0.7
6	25	4.7	4.8	3.3	3.2	2.5	2.6	1.9	2.1	1.6	1.5	1.3	1.2	1.1	0.7	1.0	0.4
	40	7.4	7.7	5.1	5.1	3.8	4.0	2.9	3.3	2.4	2.4	2.2	1.9	1.7	1.0	1.5	0.6
	60	12.4	12.9	8.6	8.4	6.3	6.8	4.7	5.5	3.9	3.8	3.4	3.0	2.9	1.5	2.7	0.9
7	25	4.1	4.1	2.9	2.9	2.2	2.3	1.7	1.9	1.4	1.4	1 2	1.2	0.9	0.7	0.8	0.5
	40	6.5	6.7	4.7	4.4	3.4	3.6	2.7	3.0	2.1	2.3	2.0	1.9	1.4	1.1	1.2	0.7
	60	10.8	11.2	7.7	7.3	5.6	6.0	4.4	5.0	3.5	3.6	3.0	3.1	2.4	1.7	2.1	1.0
8	25	3.6	3.6	2.7	2.6	2.0	2.1	1.6	1.8	1.3	1.3	1.1	1.1	0.8	0.8	0.7	0.5
	40	5.7	5.8	4.2	4.1	3.2	3.3	2.5	2.8	1.9	2.0	1.9	1.8	1.2	1.2	1.0	0.8
	60	9.7	9.5	7.0	6.8	5.3	5.5	4.1	4.6	3.3	3.4	2.8	3.0	2.1	1.9	1 7	1.2
10	25	2.8	2.8	2.2	2.1	1.68	1.8	1.3	1.4	1.1	1.1	1.0	1.0	0.7	0.7	0.5	0.5
	40	4.5	4.6	3.6	3.3	2.7	2.7	2.1	2.3	1.8	1.8	1.6	1.6	1.1	1.1	0.8	0.8
	60	7.6	7.9	5.8	5.4	4.5	4.5	3.6	3.8	2.9	3.0	2.6	2.6	1.7	1.8	1.4	1.3
12	25	2.2	2.2	1.8	1.7	1.4	1.4	1.2	1.2	0.9	1.0	0.8	0.9	0.5	0.6	.04	0.5
	40	3.6	3.8	2.8	2.8	2.3	2.3	1.9	1.9	1.5	1.6	1.4	1.4	0.9	1.0	.07	0.8
	60	6.1	6.4	4.8	4.6	3.8	3.8	3.1	3.4	2.5	2.6	2.3	2.2	1.5	1.6	1.2	1.2

TABLE VIII

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 25, 40 AND 60 WATT MAZDA OR TUNGSTEN LAMPS ARRANGED IN 3 ROWS AT HEIGHTS AND DISTANCES APART EACH WAY AS GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,125, 106,130 AND 106,150 RESPECTIVELY.

DISTANCE APART OF LAMPS

Height of lamp in feet above plane to be illuminated.	Wattage	3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Bet'w'en l'mps	Under l'mps	Bet'w'en l'mps	Under l'mps	Bet'w'en l'mps	Under l'mps	Bet'w'en l'mps
4	25	8.6	8.1	5.4	4.6	3.9	3.4	3.1	2.4	2.6	1.4	2.4	1.1	2.1	0.5	2.1	0.3
	40	14.3	12.6	8.8	7.4	6.5	5.3	5.2	3.6	4.7	2.1	4.3	1.6	4.0	0.7	3.9	0.4
	60	22.4	20.8	18.4	11.8	9.6	8.4	7.7	5.6	6.8	3.2	6.3	2.4	5.9	1.0	5.7	0.5
5	25	7.6	7.1	5.0	4.3	3.5	3.3	2.7	2.5	2.1	1.6	1.9	1.3	1.6	0.6	1.4	0.4
	40	12.3	11.0	7.8	6.8	5.1	5.1	3.9	3.9	3.2	2.1	3.1	1.6	2.3	0.9	2.2	0.5
	60	20.3	18.0	12.5	11.1	8.4	8.2	6.4	6.2	5.3	3.6	4.7	2.8	4.0	1.4	3.8	0.7
6	25	6.6	6.2	4.5	3.9	3.2	3.0	2.4	2.4	1.9	1.6	1.5	1.4	1.2	0.7	1.0	0.4
	40	10.6	9.8	7.0	6.1	5.0	4.6	3.6	3.6	2.9	2.5	2.4	2.1	1.9	1.1	1.6	0.6
	60	17.7	16.3	11.7	9.9	8.1	7.6	5.8	6.0	4.5	4.1	3.9	3.2	3.0	1.6	2.8	0.9
7	25	5.8	5.5	4.1	3.6	3.0	2.7	2.2	2.2	1.7	1.6	1.4	1.3	1.0	0.8	0.9	0.5
	40	9.3	8.8	6.5	5.5	4.6	4.3	3.4	3.4	2.6	2.5	2.2	2.0	1.5	1.1	1.3	0.7
	60	15.6	14.6	10.7	9.0	7.5	6.9	5.6	5.5	4.3	3.9	3.5	3.3	2.6	1.8	2.3	1.1
8	25	5.2	4.9	4.0	3.3	2.8	2.6	2.1	2.1	1.7	1.5	1.4	1.3	1.0	0.8	0.8	0.5
	40	8.3	7.9	5.9	5.3	4.4	4.0	3.3	3.3	2.6	2.3	2.1	2.0	1.4	1.3	1 1	0.8
	60	14.0	12.9	9.8	8.7	7.2	6.6	5.4	5.3	4.2	3.8	3.4	3.2	2.4	2.0	1.9	1.3
10	25	4.0	4.0	3.1	2.8	2.4	2.3	1.8	1.8	1.4	1.3	1.3	1.1	0.9	0.7	0.7	0.6
	40	6.6	6.5	5.2	4.5	3.8	3.5	3.0	2.8	2.4	2.1	1.9	1.9	1.3	1.2	1.1	0.9
	60	11.1	10.9	8.3	7.3	6.3	5.7	4.9	4.6	3.8	3.5	3.1	2.9	2.1	1.9	1.6	1.4
12	25	3.2	3.2	2.6	2.4	2.0	1.9	1.7	1.8	1.3	1.2	1.1	1.0	0.8	0.7	0.6	0.5
	40	5.2	5.4	4.1	3.8	3.3	3.1	2.6	2.4	2.2	1.9	1.7	1.6	1.2	1.1	0.9	0.9
	60	8.8	9.0	6.9	6.4	5.5	5.0	4.3	4.3	3.5	3.1	2.9	2.6	2.0	1.8	1.5	1.3

TABLE IX

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 25, 40 AND 60 WATT MAZDA OR TUNGSTEN LAMPS ARRANGED IN FOUR ROWS AT HEIGHTS AND DISTANCES APART EACH WAY AS GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,125, 106,130 AND 106,150 RESPECTIVELY.

DISTANCE APART OF LAMPS.

Height of lamp above plane illuminated.	Wattage	3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps
4	25	9.2	9.2	5.7	5.1	4.0	3.6	3.2	2.5	2.7	1.5	2.4	1.2	2.1	0.5	2.1	0.3
	40	15.2	14.2	9.2	9.0	6.7	5.6	5.3	3.8	4.8	2.2	4.3	1.7	4.0	0.8	3.9	0.4
	60	23.6	23.2	13.9	12.8	9.9	8.9	7.9	5.8	6.9	3.4	6.3	2.6	5.9	1.1	5.7	0.6
5	25	8.4	8.4	5.4	4.9	3.7	3 6	2.8	2.7	2.2	1.7	1.9	1.4	1.6	0.7	1.4	0.4
	40	13.3	12.8	8.3	7.6	5.3	5.6	4.0	4.2	3.3	2.5	3.1	1.9	2.3	1.0	2.2	0.6
	60	21.8	20.9	13.1	12.4	8.7	8.9	6.6	6.5	5.4	3.8	4.8	3.0	4.0	1.4	3.8	0.7
6	25	7.5	7.6	4.9	4.6	3.4	3.4	2.5	2.6	2.0	1.8	1.5	1.5	1.2	0.8	1.0	0.4
	40	11.8	11.9	7.6	7.1	5.3	5.0	3.7	3.8	3.0	2.7	2.4	2.2	1.9	1.2	1.6	0.6
	60	19.6	19.6	12.6	11.5	8.5	8.4	6.0	6.4	4.6	4.3	4.0	3.3	3.0	1.7	2.8	1.0
7	25	6 7	6.8	4.5	4.4	3.2	3.1	2.3	2.5	1.8	1.7	1.4	1.4	1.0	0.8	0.9	0.5
	40	10.6	10.9	7 1	6.6	4.9	4.9	3.6	3.8	2.7	2.7	2.3	2.2	1.5	1.2	1.3	0.7
	60	17.6	18.0	11.7	10.8	8.0	7.9	5.9	6.1	4.5	4.2	3.6	3.5	2.7	1.9	2.3	1.1
8	25	6.4	6.2	4.5	4.1	3.1	3.0	2.3	2.4	1.8	1.7	1.4	1.4	1.0	0 9	0.8	0.6
	40	9.8	9.9	6.7	6.5	4.8	4.8	3.5	3.6	2.7	2.5	2.2	2.1	1.4	1.4	1.1	0.9
	60	16.3	16.3	11.0	10.6	7.9	7.7	5.7	5.9	4.4	4.2	3.5	3.5	2.5	2.1	1.9	1.3
10	25	4.9	5.1	3.7	3.6	2.7	2.8	2.0	1.4	1.5	1.5	1.4	1.3	0.9	0.8	0.7	0.6
	40	8.0	8.3	6.0	5.7	4.3	4.3	3.3	3.3	2.6	2.4	2.0	2.1	1.4	1.3	1.0	1.0
	60	13.4	14.0	9.7	9.2	7.1	7.0	5.3	5.4	4.0	4.0	3.1	3.2	2.2	2.1	1.6	1.4
12	25	4.0	4.2	3.1	3.0	2.3	2.4	1.9	1.2	1.4	1.4	1.2	1.2	0.8	0.8	0.6	0.6
	40	6.4	6.9	4.9	4.8	3.8	3.9	2.9	2.9	2.4	2.3	1.8	1.8	1.3	1.2	0.9	0.9
	60	10.9	11.6	8.3	8.2	6.3	6.3	4.8	5.2	3.8	3.7	2.9	3.0	2.1	2.0	1.5	1.4

TABLE X

TABLE SHOWING ILLUMINATION IN FOOT CANDDLES FROM 100, 150 AND 250 WATTS MAZDA LAMPS ARRANGED IN ONE ROW AT HEIGHTS AND DISTANCES APART GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,180, 106,185 AND 106,190 RESPECTIVELY.

DISTANCE APART OF LAMPS IN FEET.

Height of unit above plane illuminated.	Wattage	6 Ft.		8 Ft.		10 Ft.		12 Ft.		14 Ft.		16 Ft.		18 Ft.		20 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps	Under l'mps	Between l'mps
6	00	5.4	5.3	4.3	3.7	3.8	2.7	3.7	1.8	3.6	1.2	3.5	0.8	3.5	0.5	3.4	0.4
	150	9.5	9.4	7.5	6.7	6.7	4.6	6.4	3.2	6.2	2.1	6.0	1.5	6.0	1.0	6.0	0.7
	250	16	16	13	11	12	8.0	11	5.4	11	3.8	11	2.7	10	1.9	10	1.3
7	100	4.6	4.7	3.6	3.4	3.0	2.6	2.8	1.9	2.7	1.4	2.6	1.0	2.6	0.7	2.6	0.5
	150	8.0	8.2	6.2	6.0	5.3	4.4	4.9	3.2	4.7	2.4	4.5	1.7	4.5	1.3	4.4	0.9
	250	14	14	11	10	9.2	7.6	8.5	5.4	8.2	4.1	8.0	3.0	7.9	2.2	7.7	1.6
8	100	4.0	4.0	3.2	3.0	2.5	2.4	2.3	1.9	2.1	1.4	2.0	1.1	2.0	0.8	2.0	0.6
	150	7.0	7.1	5.3	5.3	4.4	4.1	4.0	3.1	3.7	2.4	3.5	1.8	3.5	1.4	3.4	1.0
	250	12	12	9.4	9.2	7.7	7.0	6.9	5.3	6.5	4.1	6.3	3.2	6.2	2.5	6.0	1.8
9	100	3.5	3.6	2.7	2.6	2.2	2.1	1.9	1.7	1.7	1.4	1.6	1.1	1.6	0.9	1.6	0.7
	150	6.2	6.3	4.6	4.7	3.8	3.7	3.4	2.9	3.1	2.3	2.9	1.9	2.8	1.5	2.7	1.1
	250	11	11	8.2	8.2	6.6	6.5	5.8	5.0	5.4	4.0	5.1	3.2	5.0	2.6	4.8	1.9
10	100	3.2	3.2	2.4	2.4	2.0	1.9	1.7	1.6	1.5	1.3	1.4	1.1	1.3	0.9	1.3	0.7
	150	5.6	5.6	4.1	4.2	3.4	3.4	3.0	2.7	2.6	2.2	2.4	1.8	2.3	1.5	2.3	1.2
	250	9.6	9.8	7.3	7.4	5.9	5.9	5.0	4.7	4.6	3.8	4.4	3.2	4.2	2.6	4.0	2.0
12	100	2.6	2.6	2.0	2.1	1.6	1.6	1.4	1.4	1.2	1.1	1.0	1.0	1.0	0.8	0.9	0.7
	150	4.5	4.6	3.4	3.5	2.7	2.8	2.4	2.3	2.1	2.0	1.8	1.7	1.7	1.5	1.7	1.2
	250	7.9	8.0	6.0	6.0	4.8	4.9	4.0	4.0	3.7	3.4	3.4	3.0	3.2	2.6	2.9	2.1
14	100	2.2	2.2	1.8	1.7	1.4	1.4	1.2	1.2	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7
	150	3.8	3.9	2.8	2.9	2.3	2.4	2.1	2.0	1.8	1.7	1.5	1.6	1.4	1.4	1.3	1.1
	250	6.6	6.8	5.1	5.0	4.0	4.1	3.4	3.4	3.1	3.0	2.8	2.7	2.6	2.4	2.3	2.0

TABLE XI

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 100, 150 AND 250 WATTS MAZDA LAMPS ARRANGED IN TWO ROWS AT HEIGHTS AND DISTANCES APART GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,180, 106,185, AND 106,190 RESPECTIVELY.

DISTANCE APART OF LAMPS.

Height of lamps in feet above plane illuminated.	Wattage	6 Ft.		8 Ft.		10 Ft.		12 Ft.		14 Ft.		16 Ft.		18 Ft.		20 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Bet'en l'mps	Under l'mps	Bet'en l'mps	Under l'mps	Bet'en l'mps	Under l'mps	Bet'en l'mps
6	100	7.03	7.88	5.01	4.66	4.19	2.46	3.95	1.34	3.69	0.76	3.59	0.60	3.52	0.34	3.49	0.30
	150	12.6	14.1	8.81	8.18	7.33	4.44	6.74	2.54	6.36	1.56	6.20	1.12	6.10	0.68	6.03	0.50
	250	21.6	24.2	15.4	14.0	12.9	7.94	11.6	4.56	11.15	2.80	10.9	1.98	10.7	1.15	10.5	0.84
7	100	6.53	7.16	4.45	4.64	3.45	2.79	3.10	1.66	2.84	0.90	2.72	0.70	2.66	0.48	2.63	0.35
	150	11.4	12.9	7.72	8.06	6.09	4.89	5.86	2.98	4.93	1.88	4.73	1.34	4.59	0.77	4.51	0.62
	250	19.6	22.3	13.7	13.7	10.6	8.52	9.28	5.24	8.57	3.32	8.30	2.40	8.07	1.40	7.82	1.04
8	100	6.01	6.60	4.14	4.32	3.00	2.95	2.55	1.86	2.29	1.10	2.16	0.86	2.07	0.47	2.04	0.39
	150	10.5	11.6	7.03	7.72	5.34	4.94	4.52	3.24	4.01	2.16	3.77	1.60	3.62	0.94	3.53	0.70
	250	18.2	20.2	12.4	13.3	9.4	9.04	7.80	5.64	6.98	3.84	6.68	2.80	6.40	1.66	6.10	1.20
9	100	5.46	6.00	3.77	4.06	2.72	2.83	2.17	1.94	1.89	1.26	1.77	0.98	1.65	0.55	1.63	0.43
	150	9.7	10.6	6.49	7.22	4.85	4.86	3.98	3.34	3.40	2.36	3.13	1.76	2.95	1.06	2.84	0.82
	250	16.8	18.3	11.5	12.5	8.47	8.54	6.85	5.80	5.95	4.12	5.59	3.10	5.27	1.87	4.92	1.40
10	100	5.12	5.48	3.52	3.82	2.62	2.72	2.04	1.96	1.71	1.40	1.52	1.08	1.42	0.64	1.39	0.52
	150	9.00	9.6	6.05	6.76	4.49	4.71	3.62	3.36	2.99	2.48	2.71	1.90	2.49	1.19	2.37	0.90
	250	15.6	16.6	9.63	11.7	7.88	8.26	6.21	5.80	5.26	4.36	4.87	3.34	4.50	2.09	4.11	1.56
12	100	4.46	4.52	3.16	3.26	2.25	2.44	1.82	1.82	1.40	1.36	1.20	1.20	1.10	0.76	1.01	0.60
	150	7.73	8.00	5.30	5.84	4.00	4.29	3.18	3.22	2.52	2.56	2.19	2.02	1.92	1.33	1.78	1.06
	250	13.5	13.8	9.35	10.2	6.98	7.56	5.39	5.52	4.43	4.44	4.01	3.48	3.55	2.36	3.07	1.84
14	100	3.86	3.88	2.83	2.92	2.11	2.14	1.65	1.68	1.31	1.32	1.11	1.20	0.93	0.82	0.87	0.74
	150	6.76	6.68	4.67	5.12	3.61	3.79	2.92	2.96	2.25	2.48	1.90	1.98	1.64	1.43	1.45	1.14
	250	11.7	11.7	8.35	8.8	6.30	6.82	4.85	5.14	3.98	4.32	3.51	3.46	3.05	2.47	2.48	1.96

only been reduced about ½ or to 4 foot candles, whereas according to the law of inverse squares it should be only 1/9th of 9.2, as is the case where the illumination of a single lamp is considered. This discrepancy is due to the fact that, although the light from each lamp is weakened exactly in proportion as the square of the distance of the plane illuminated from the source of light increases, there is an increase of illumination under it from surrounding lights. As a matter of fact, if it were possible to confine all of the light to the floor in a large space illuminated by many small lamps close together, the intensity of the illumination on the floor would be independent of the height of the sources of light above it.

Tables XII and XIII have been prepared especially to facilitate calculations of illumination by the point by point method from miscellaneous photometric curves for lamps arranged in one row.

To find the foot candles obtainable with lamps at given elevations above the plane illuminated and given distances apart and arranged in one row we consult the table under which those figures are given.

The method can be best illustrated by an example: Suppose we wish to find the foot candles obtainable from a certain unit (lamp and reflector) of which we have the photometric curve. Said units to be arranged in one row, as over a long sewing table, for instance, and 4 feet above table, lamps spaced 3 feet apart. We consult table XII and in the division headed by 4 feet select the vertical column pertaining to lamps 3 feet apart. In this column we find at the left the degree numbers 37, 56, and 66. These

TABLE XII

TABLE FOR CALCULATING ILLUMINATION FROM ONE ROW OF LAMPS AT HEIGHTS AND DISTANCES GIVEN. FOR USE WITH ANY PHOTOMETRIC CURVE

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 4 FEET

Distance between lamps	°	3	°	3	°	4	°	5	°	6	°	7	°	8	°	9	°	10	°	12
Under lamps	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625	0	.0625
	27	.0884	37	.0634	45	.0442	51	.0310	56	.0219	60	.0156	63	.0117	66	.0084	68	.0065	72	.0037
	45	.0442	56	.0219	63	.0117	68	.0065	72	.0037	74	.0026	76	.0018	77	.0014	79	.0008	81	.0005
	56	.0219	66	.0084	72	.0037	75	.0022	77	.0014	79	.0008	81	.0005	82	.0003	82	.0003	84	.00014
Between lamps	14	.1162	21	.1017	27	.0884	32	.0762	37	.0634	41	.0537	45	.0442	48	.0374	51	.0310	56	.0219
	37	.0634	48	.0374	56	.0219	62	.0131	66	.0084	69	.0057	72	.0037	73	.0031	75	.0022	77	.0014
	51	.0310	62	.0131	68	.0065	72	.0037	75	.0022	77	.0014	79	.0008	80	.0006	81	.0005	82	.0003

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 5 FEET

Distance between lamps	°	3	°	4	°	5	°	6	°	7	°	8	°	9	°	10	°	12	°	14
Under lamp	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400	0	.0400
	31	.0504	39	.0375	45	.0283	50	.0212	54	.0162	58	.0119	61	.0091	63	.0075	67	.0048	70	.0032
	50	.0212	58	.0119	63	.0075	67	.0048	70	.0032	73	.0020	74	.0016	76	.0011	78	.0007	80	.0004
	61	.0091	67	.0048	72	.0024	74	.0016	77	.0009	78	.0007	80	.0004	81	.0003	82	.0002	83	.00014
Between lamps	17	.0699	22	.0638	27	.0566	31	.0504	35	.0440	39	.0375	42	.0328	45	.0283	50	.0212	54	.0162
	42	.0328	50	.0212	56	.0140	61	.0091	65	.0060	67	.0048	70	.0032	72	.0024	74	.0016	77	.0009
	56	.0140	63	.0075	68	.0042	72	.0024	74	.0016	76	.0011	77	.0009	79	.0005	81	.0003	82	.0002

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 6 FEET

Distance between lamps	°	4	°	5	°	6	°	7	°	8	°	9	°	10	°	12	°	14	°	16
Under lamps	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278	0	.0278
	34	.0317	40	.0248	45	.0196	49	.0157	53	.0121	56	.0097	59	.0076	63	.0052	67	.0033	69	.0025
	53	.0121	59	.0076	63	.0052	67	.0033	69	.0025	72	.0016	73	.0014	76	.0008	78	.0005	79	.0004
	63	.0052	68	.0029	72	.0016	74	.0012	76	.0008	77	.0006	79	.0004	81	.0003	82	.00015	83	.0001
Between lamps	18	.0458	23	.0433	27	.0383	30	.0366	34	.0317	37	.0283	40	.0248	45	.0196	49	.0157	53	.0121
	45	.0196	51	.0138	56	.0097	60	.0069	63	.0052	66	.0037	68	.0029	72	.0016	74	.0012	76	.0008
	59	.0076	64	.0047	68	.0029	71	.0019	73	.0014	75	.0010	77	.0006	79	.0004	80	.0003	81	.0002

Read photometric curve at angles given and multiply c. p. thus found by number in table opposite degree; adding these results will give foot candles obtainable under or between lamps.

TABLE XIII.

TABLE FOR CALCULATING ILLUMINATION FROM ONE ROW OF LAMPS AT HEIGHTS AND DISTANCES GIVEN. FOR USE WITH ANY PHOTOMETRIC CURVE

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 8 FEET

Distance between lamps	°	6	°	7	°	8	°	9	°	10	°	12	°	14	°	16	°	18
Under lamps	0	.01562	0	.01562	0	.01562	0	.01562	0	.01562	0	.01562	0	.01562	0	.01562	0	.01562
	37	.01590	41	.01344	45	.01104	48	.00934	51	.00778	56	.00549	60	.00391	63	.00292	66	.00210
	56	.00549	60	.00391	63	.00292	66	.00210	68	.00164	72	.00092	74	.00065	76	.00044	77	.00036
	66	.00210	69	.00144	72	.00092	73	.00078	75	.00054	77	.00036	79	.00021	81	.00012	82	.00008
Between lamps	21	.02537	24	.02381	27	.02209	29	.02092	32	.01910	37	.01590	41	.01344	45	.01104	48	.00934
	48	.00934	53	.00681	56	.00549	59	.00431	62	.00322	66	.00210	69	.00144	72	.00092	73	.00078
	62	.00322	65	.00236	68	.00164	70	.00125	72	.00092	75	.00054	77	.00036	79	.00021	80	.00016

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 9 FEET

Distance between lamps	°	7	°	8	°	9	°	10	°	12	°	14	°	16	°	18	°	20
Under lamps	0	.01235	0	.01235	0	.01235	0	.01235	0	.01235	0	.01235	0	.01235	0	.01235	0	.01235
	38	.01207	42	.01012	45	.00872	48	.00738	53	.00638	57	.00397	61	.00281	63	.00221	66	.00166
	57	.00397	61	.00281	63	.00221	66	.00166	69	.00114	72	.00073	74	.00052	76	.00035	77	.00028
	67	.00147	69	.00114	72	.00073	73	.00062	76	.00035	78	.00022	79	.00017	81	.00009	81	.00009
Between lamps	21	.02010	24	.01881	27	.01746	29	.01652	34	.01407	38	.01207	42	.01012	45	.00872	48	.00738
	49	.00696	53	.00538	56	.00432	59	.00338	63	.00221	67	.00147	69	.00114	72	.00073	73	.00062
	63	.00221	66	.00166	68	.00130	70	.00099	73	.00062	76	.00035	77	.00028	79	.00017	80	.00013

HEIGHT OF LAMPS ABOVE PLANE ILLUMINATED 10 FEET

Distance between lamps	°	8	°	9	°	10	°	12	°	14	°	16	°	18	°	20	°	22
Under lamps	0	.010	0	.010	0	.010	0	.010	0	.010	0	.010	0	.010	0	.010	0	.010
	39	.00938	42	.00820	45	.00706	50	.00530	54	.00406	58	.00298	61	.00228	63	.00187	66	.00134
	58	.00298	61	.00228	63	.00187	67	.00119	70	.00080	73	.00050	74	.00042	76	.00028	77	00023
	67	.00119	70	.00080	72	.00059	74	.00042	77	.00023	78	.00018	79	.00014	81	.00008	81	.00008
Between lamps	22	.01594	24	.01524	27	.01414	31	.01260	35	.01100	39	.00938	42	.00820	45	.00706	48	.00598
	50	.00530	53	.00436	56	.00350	61	.00228	65	.00151	67	.00119	70	.00080	72	.00059	73	.00050
	63	.00187	66	.00184	68	.00105	72	.00059	74	.00042	76	.00028	77	.00023	79	.00014	80	.00010

Read photometric curve at angles given and multiply c. p. thus found by number in table opposite degree; adding these results will give foot candles obtainable under or between lamps.

numbers denote the degrees in the photometric curve at which the candle power must be read. The candle power found at these various angles are now each to be multiplied by the decimal number set opposite the corresponding degree. Thus the candle power found directly beneath lamp at 0 degrees must be multiplied by .0625, that at 37 by .0634, that at 56 by .0219, etc. The results so obtained must then be added and their sum will give us the foot candles

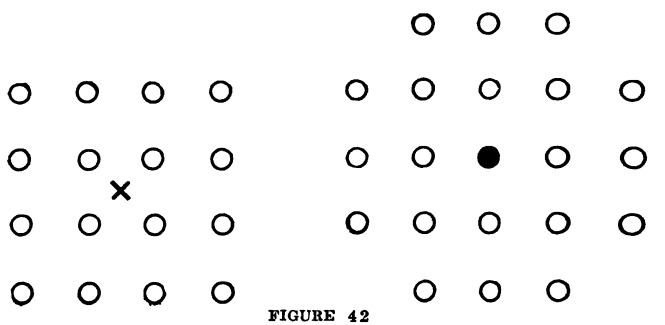

FIGURE 42

that will be found directly under each one of a row of lamps corresponding to the elevation and distance apart considered.

The intensity existing at points between lamps can be found in the same manner, using the horizontal division designated "Between lamps" for that purpose.

For the rapid calculation of illumination to be used in large spaces such as department stores, shipping rooms, etc., where units can be arranged in squares, Tables XIV to XVI will be found very con-

venient. These tables can be used in connection with any photometric curve of arc, Nernst or incandescent lamps.

The illumination referred to in the tables as "Under lamps" is that indicated in the center of the 21 lamps at the left of Figure 42 and that "Between lamps" is the intensity at a point indicated by cross in center of 16 lamps shown at the right of the same figure.

The figures given in the tables are quite close approximations and will be found sufficiently reliable for all practical purposes. The influence of reflection has not been taken into account.

The tables give the angles at which the photometric curve must be read and certain decimal numbers by which the candle power found at the corresponding angle must be multiplied.

As an example: To find the illumination that would exist under a certain lamp located in the center of a large space and surrounded by other lamps placed in squares 8 feet apart and 4 feet above the plane to be illuminated; we find the candle power directly beneath lamp in curve and multiply by .0625. This represents the contribution of one lamp indicated by black circle. Next we read the curve at 63 degrees and multiply by .0211. This represents the contribution of 4 lamps nearest to center lamp. Next read curve at 70 degrees and multiply by .0100. This represents the contribution of 4 other lamps equal distances from center lamp. Lastly we read at 76 degrees and multiply by .0108. This represents the contribution of 12 lamps farthest away.

TABLE XIV

TABLE FOR CALCULATING ILLUMINATION OBTAINABLE FROM LAMPS ARRANGED IN SQUARES.

Height of unit above plane illuminated.	8 foot squares				10 foot squares				12 foot squares				14 foot squares			
	Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps	
	Angle		Angle		Angle		Angle		Angle		Angle		Angle		Angle	
4	0	.0625	56	.0437	0	.0625	60	.0312	0	.0625	65	.0188	0	.0625	68	.0131
	63	.0211	72	.0147	68	.0131	76	.0070	72	.0074	78	.0044	74	.0052	81	.0013
	70	.0100	77	.0028	74	.0052	79	.0017	77	.0028	81	.0009	79	.0017	82	.0006
	76	.0108			79	.0052			82	.0020			81	.0028		
5	0	.040	50	.2650	0	.040	54	.0325	0	.040	60	.0200	0	.0400	64	.0134
	58	.0238	67	.0596	64	.0135	73	.0080	67	.0095	75	.0056	70	.0064	79	.0022
	66	.0108	74	.0209	70	.0064	77	.0018	74	.0033	79	.0011	76	.0023	81	.0006
	73	.0120			77	.0055			79	.0033			80	.0025		
6	0	.0277	45	.0391	0	.0277	50	.0294	0	.0277			0	.0277	59	.0152
	53	.0242	63	.0207	59	.0152	70	.0089	64	.0093	55	.0209	67	.0066	76	.0031
	61	.0126	70	.0044	67	.0066	74	.0023	70	.0044	73	.0056	73	.0028	79	.0008
	69	.0153			74	.0069			78	.0029	77	.0013	78	.0030		
8	0	.0156	37	.0318	0	.0153	41	.0268	0	.0156	47	.0190	0	.0156	51	.0155
	45	.0220	55	.0236	51	.0155	64	.0105	56	.0109	67	.0074	60	.0075	72	.0037
	54	.0127	64	.0053	60	.0077	70	.0025	65	.0047	73	.0016	68	.0033	75	.0011
	63	.0175			69	.0086			74	.0039			74	.0039		
10	0	.0100	31	.0252	0	.0100	35	.0220	0	.0100	40	.0180	0	.0100	45	.0141
	39	.0188	50	.0212	45	.0141	58	.0119	50	.0106	62	.0082	54	.0081	68	.0042
	47	.0127	60	.0050	54	.0081	65	.0030	60	.0050	69	.0018	65	.0030	71	.0014
	58	.0179			65	.0091			69	.0055			70	.0048		
12	0	.0069	27	.0195	0	.0069	30	.0179	0	.0069	35	.0152	0	.0069	40	.0124
	34	.0158	45	.0195	39	.0129	53	.0120	45	.0097	58	.0082	50	.0073	64	.0046
	43	.0108	55	.0052	50	.0072	60	.0084	55	.0052	66	.0018	59	.0038	68	.0014
	53	.0171			60	.0103			66	.0056			67	.0049		

Read "Curve" at angles given, multiply by numbers set opposite and add results.

TABLE XV

TABLE FOR CALCULATING ILLUMINATION OBTAINABLE FROM LAMPS ARRANGED IN SQUARES.

Height of lamps above plane illuminated.	16 foot squares				18 foot squares				20 foot squares				22 foot squares			
	Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps	
	Angle		Angle		Angle		Angle		Angle		Angle		Angle		Angle	
4	0	.0625	71	.0095	0	.0625	73	.0062	0	.0625	74	.0052	0	.0625	75	.0039
	76	.0035	81	.0019	77	.0025	82	.0014	79	.0020	83	.0009	80	.0014	84	.0007
	80	.0013	83	.0004	80	.0013	84	.0003	82	.0007	85	.0002	83	.0005	85	.0001
	83	.0015			83	.0011			84	.0008			85	.0006		
5	0	.0400	66	.0108	0	.0400	68	.0078	0	.0400	70	.0060	0	.0400	72	.0047
	73	.0042	79	.0022	74	.0030	80	.0017	76	.0023	81	.0012	77	.0018	82	.0008
	77	.0016	82	.0005	79	.0011	82	.0004	80	.0008	83	.0008	81	.0006	84	.0002
	81	.0017			82	.0018			83	.0009			83	.0007		
6	0	.0277	62	.0114	0	.0277	65	.0083	0	.0277	67	.0066	0	.0277	69	.0051
	69	.0048	77	.0025	72	.0033	78	.0020	73	.0026	79	.0013	75	.0020	81	.0009
	75	.0019	80	.0006	76	.0014	81	.0038	78	.0010	82	.0003	79	.0008	83	.0002
	79	.0022			80	.0015			81	.0011			82	.0008		
8	0	.0156	55	.0118	0	.0156	58	.0092	0	.0156	60	.0078	0	.0156	62	.0063
	64	.0053	73	.0032	66	.0042	74	.0026	68	.0033	76	.0018	70	.0025	78	.0012
	70	.0028	77	.0007	72	.0018	78	.0006	74	.0014	79	.0004	75	.0009	80	.0003
	76	.0026			77	.0019			79	.0015			80	.0010		
10	0	.0100	49	.0113	0	.0100	52	.0093	0	.0100	54	.0078	0	.0100	57	.0064
	58	.0060	69	.0040	61	.0046	71	.0028	64	.0034	73	.0022	66	.0027	75	.0014
	66	.0027	74	.0009	68	.0021	75	.0007	70	.0015	77	.0005	72	.0012	78	.0004
	78	.0031			74	.0023			76	.0017			77	.0013		
12	0	.0069	43	.0106	0	.0069	46	.0092	0	.0069	49	.0078	0	.0069	52	.0062
	53	.0060	65	.0042	56	.0048	67	.0035	59	.0038	69	.0024	61	.0030	72	.0016
	62	.0030	70	.0010	65	.0021	72	.0008	67	.0016	74	.0006	69	.0013	76	.0004
	69	.0036			72	.0024			73	.0019			75	.0015		

Read "Curve" at angles given, multiply by numbers set opposite and add results.

TABLE XVI

TABLE FOR CALCULATING ILLUMINATION OBTAINABLE FROM LAMPS ARRANGED IN SQUARES.

Height of unit above plane illuminated.	24 Ft. Squares				26 Ft. Squares				28 Ft. Squares				30 Ft. Squares			
	Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps		Under lamps		Between lamps	
	Angle		Angle		Angle		Angle		Angle		Angle		Angle		Angle	
8	0	.0156	65	.0050	0	.0156	66	.0040	0	.0156	68	.0032	0	.0156	69	.0028
	72	.0020	78	.0011	73	.0013	80	.0006	74	.0013	81	.0005	75	.0011	81	.0005
	77	.0007	81	.0002	78	.0006	82	.0002	79	.0005	82	.0001	79	.0004	83	.0001
	81	.0008			81	.0007			82	.0006			82	.0004		
10	0	.0100	60	.0050	0	.0100	61	.0045	0	.0100	64	.0036	0	.0100	65	.0032
	67	.0022	75	.0014	69	.0018	78	.0007	70	.0015	79	.0006	72	.0013	79	.0006
	74	.0009	79	.0003	75	.0007	80	.0002	76	.0006	81	.0002	77	.0005	81	.0001
	78	.0009			79	.0008			80	.0007			81	.0005		
12	0	.0069	55	.0052	0	.0069	57	.0044	0	.0069	59	.0038	0	.0069	60	.0034
	64	.0025	73	.0016	65	.0021	76	.0008	67	.0016	76	.0008	68	.0014	77	.0007
	71	.0010	77	.0003	72	.0008	78	.0003	73	.0007	79	.0002	74	.0006	79	.0002
	76	.0012			77	.0009			77	.0009			79	.0006		
14	0	.0051	50	.0058	0	.0051	53	.0044	0	.0051	55	.0039	0	.0051	56	.0035
	60	.0026	70	.0017	62	.0022	73	.0009	64	.0018	74	.0009	65	.0015	74	.0008
	68	.0012	75	.0004	69	.0009	76	.0003	71	.0007	77	.0002	72	.0006	78	.0002
	74	.0014			75	.0010			76	.0009			77	.0007		
16	0	.0039	47	.0050	0	.0039	49	.0044	0	.0039	51	.0038	0	.0039	53	.0034
	56	.0027	67	.0019	58	.0028	71	.0010	60	.0019	72	.0009	62	.0018	72	.0009
	65	.0012	73	.0004	67	.0010	74	.0003	68	.0008	75	.0003	69	.0007	76	.0002
	72	.0014			73	.0012			74	.0010			75	.0008		
18	0	.0031	43	.0048	0	.0031	45	.0043	0	.0031	48	.0038	0	.0031	49	.0034
	53	.0027	65	.0020	56	.0023	69	.0011	57	.0020	70	.0010	60	.0016	70	.0010
	62	.0013	71	.0004	64	.0010	72	.0004	65	.0009	73	.0003	67	.0008	74	.0003
	69	.0016			71	.0013			72	.0011			73	.0009		

Read "Curve" at angles given, multiply by numbers set opposite and add results.

Adding all of the results so obtained we have the full illumination of the 21 lamps considered, near enough for all practical purposes. In the same manner we can test the evenness of the illumination by the same process using the figures in column "Between lamps."

CHAPTER XVIII

INCANDESCENT LIGHT WIRING AND OTHER TABLES

Table XVII is intended to facilitate the selection of the smallest wire having the necessary carrying capacity for a given number of lights. As all incandescent lamps are now rated in watts the number of watts a given wire at a given voltage can accommodate is stated instead of the number of amperes as was formerly customary. To find the smallest wire allowable for a given load, we first find the number of watts this load amounts to and under the proper voltage find the number nearest equal to this. Opposite this number at the left will be found the gauge number of the wire.

Example: We have 280 25-watt lamps to install; voltage 110. What is the smallest wire allowable? 25 times 280 equals 7000; tracing down in the column under "Watts" we find 7150 and opposite this at the left the number 4, which indicates that a number 4 B. & S. gauge wire is the smallest wire we shall be allowed to use under the "National Electrical Code."

But we may also wish to know what loss this wire will cause. For this purpose we have at the right of the column headed "Watts" a tabulation of the

number of feet the different wires will convey their maximum load at the percentages of loss indicate at the top under the heading "Percentage of Loss." Thus, a No. 14 wire will carry 1,320 watts at 110 volts 70 feet at a loss of 4 per cent; a No. 00 will carry 16,500 watts a distance of 90 feet at a loss of 2 per cent. The loss in mains should not exceed 2 per cent and it will be much better if it is even less. If then we find upon selecting the smallest wire that will be allowed to carry our load that the loss with this wire will be greater than is desired we proceed to select a larger wire.

To aid in the selection of this wire another tabulation has been made at the right under the heading "Dividers." Here are given the sizes of wire which will divide the loss entailed by the use of the smallest permissible wire by the corresponding figures given directly under each wire. Thus, if we find that the loss caused by a number 8 wire is too great we can divide this loss by 2 by using a No. 5 wire or by 4 by using a No. 2 wire, as indicated in the table. See Rule given at top of table.

The use of the table throughout can best be made clear by an example. Suppose we have an installation of 120 100-watt lamps and we wish to find the proper size of wire to supply current to them at a voltage of 110, the distance being 300 feet and the loss not to exceed 2 per cent. We have 120 times 100, which gives us 12,000 watts. Tracing downward in the column headed watts we find 11,770 as the nearest to 12,000 and at the left we find indicated a number 1 wire.

As our distance is 300 feet, we trace along the horizontal line corresponding to 110 volts and No. 1 wire until at the right we find the number 319, and as this is in the column headed by 8 per cent loss, it indicates that our wire at this distance will cause a loss of 8 per cent. As we wish only about 2 per cent loss we must divide this loss by about 4.

To find the wire which will give us the required loss we trace along in the same horizontal division pertaining to No. 1 wire until we come to the number 4.1 which is found directly below 350,000, indicating that a 350,000 c.m. wire will give us ¼th the loss as a No. 1 wire, or carry the load 4 times as far with the loss indicated for the same wire.

The wiring table in this form is thought to be the most practical, because it deals directly with commercial sizes of wire and there is not the likelihood of selecting wires simply from loss considerations and neglecting the permissible carrying capacity as is often done with other tables.

WIRING CALCULATIONS

The circular mil is used as the basis of most wiring calculations. It is equal to the cross section of a wire having a diameter of .001 inch.

The resistance of copper wire varies with the purity and also with the conditon of the wire whether hard drawn or annealed.

For the purpose of calculating loss in wires, etc., the resistance of a copper wire one foot long and having a diameter of 1 mil (which is equivalent to a cross section of 1 circular mil) is usually taken as equivalent to 10.8 ohms.

The simplest formulas for wiring calculations are:

$$A = \frac{21.6\,I\,D}{e} \qquad e = \frac{21.6\,I\,D}{A} \qquad D = \frac{A\,e}{21.6\,I} \qquad I = \frac{A\,e}{21.6\,D}$$

Where A = area in circular mils.

Where e = volts lost in line.

Where I = current in amperes.

Where D = single distance in feet.

The following formulas will sometimes be more convenient:

$$e = \frac{2\,D\,I}{K} \qquad D = \frac{e\,K}{2\,I} \qquad \text{and} \qquad I = \frac{e\,K}{2\,D}$$

K being the number of feet, per ohm resistance of the wire given in Table XIX.

TABLE XVII. WIRING TABLE

Use Only With 100 Per Cent Power Factor

RULE—Find number of watts to be transmitted and trace down column "Watts" until nearest corresponding number is found opposite voltage to be used. At the left will be found the smallest size wire permissible under safety rules. In same line, corresponding to voltage trace along to the right until number nearest equal to distance is found. At the top of the column in which this number is found will be found the percentage of loss entailed by the wire in question. If this loss is greater than desired it may be divided by using one of the wires indicated in division at the right of the table, the divisor being given in connection with each gauge number of wire and directly below it. Thus substituting a No. 10 for a No. 14 will divide the loss by 2.5 and a 00 in place of a No. 5 by 4, etc.

TABLE XVII

National Electrical Code Carrying Capacities. Rubber Covered Wire

B. & S. Gauge	Volts	Watts	Distance in feet — Percentage of Loss						Dividers		
			2	3	4	5	6	8			
14	110	1320	35	53	70	87	105	139	12	10	8
	220	2640	70	106	139	174	209	279	1.6	2.5	4.0
12	110	1870	39	59	78	98	117	156	10	8	6
	220	3740	78	117	156	196	235	313	1.6	2.5	4.0
10	110	2640	44	66	88	110	132	176	8	5	4
	220	5280	88	132	176	220	264	352	1.6	3.1	4.0
8	110	3630	51	76	102	127	153	204	5	3	2
	220	7260	102	153	204	255	306	408	2.0	3.2	4.0
6	110	5060	58	87	116	145	174	232	3	1	0
	220	10120	116	174	232	290	349	465	2.0	3.2	4.0
5	110	5940	62	94	125	156	187	250	2	0	00
	220	11880	125	187	250	312	375	499	2.0	3.2	4.0
4	110	7150	65	98	131	164	196	262	1	00	000
	220	14300	131	196	262	327	392	523	2.0	3.2	4.0
3	110	8360	71	106	141	176	212	282	0	000	0000
	220	16720	141	212	282	353	423	564	2.0	3.2	4.0
2	110	9900	75	113	150	188	225	300	00	0000	250000
	220	19800	150	225	300	376	451	601	2.0	3.2	3.8
1	110	11770	80	119	159	199	239	319	000	250000	350000
	220	23540	159	239	319	398	478	637	2.0	3.0	4.1
0	110	13970	85	127	169	212	254	338	0000	350000	400000
	220	27940	169	254	338	423	508	677	2.0	3.0	3.8
00	110	16500	90	136	181	226	271	362	250000	400000	500000
	220	33000	181	271	362	452	542	723	1.9	3.0	3.7
000	110	19470	97	145	193	241	290	386	300000	500000	700000
	220	38940	193	290	386	483	579	772	1.7	3.0	4.1
0000	110	23100	103	154	205	257	308	411	400000	600000	800000
	220	46200	205	308	411	513	616	821	1.9	2.8	3.7
250000	110	25850	108	163	217	271	325	433	500000	750000	1000000
	220	51700	217	325	433	542	650	867	2.0	3.0	4.0
300000	110	29700	113	170	226	283	339	453	600000	900000	1200000
	220	59400	226	339	453	566	679	905	2.0	3.0	4.0
350000	110	33000	119	178	238	297	356	475	700000	1000000	1400000
	220	66000	238	356	475	594	713	951	2.0	3.0	4.0
400000	110	36300	123	185	247	309	370	493	800000	1200000	1600000
	220	72600	247	370	494	617	741	988	2.0	3.0	4.0
500000	110	42900	131	196	261	326	391	522	1000000	1500000	2000000
	220	85800	261	392	522	653	783	1045	2.0	3.0	4.0

TABLE XVIII. WIRING TABLE

Use Only With 100 Per Cent Power Factor

RULE—Find number of watts to be transmitted and trace down column "Watts" until nearest corresponding number is found opposite voltage to be used. At the left will be found the smallest size wire permissible under safety rules. In same line, corresponding to voltage trace along to the right until number nearest equal to distance is found. At the top of the column in which this number is found will be found the percentage of loss entailed by the wire in question.

If this loss is greater than desired it may be divided by using one of the wires indicated in division at the right of the table the divisor being given in connection with each gauge number of wire and directly beneath it. Thus substituting a No. 1 for a No. 4 will divide the loss by 2 and a 0000 in place of a No. 3 will divide it by 4.

TABLE XVIII

National Electrical Code Carrying Capacities. "Other Than Rubber Insulation"

B. & S. Gauge	Volts	Watts	Distance in feet — Percentage of loss						Dividers		
			2	3	4	5	6	8			
14	110	1760	26	39	52	65	78	104	12	10	8
	220	3520	52	78	105	131	156	209	1.6	2.5	4.0
12	110	2580	29	43	5	73	87	116	10	8	6
	220	5060	58	87	116	145	174	232	1.6	2.5	4.0
10	110	3520	33	50	66	83	99	132	8	5	4
	220	7040	66	99	132	165	198	264	1.6	3.1	4.0
8	110	5060	37	55	73	92	111	146	5	3	2
	220	10120	73	110	146	183	220	292	2.0	3.2	4.0
6	110	7150	41	62	82	103	123	164	3	1	0
	220	14300	82	123	164	206	246	328	2.0	3.2	4.0
5	110	8470	44	66	88	109	132	176	2	0	00
	220	16940	88	131	175	219	264	351	2.0	3.2	4.0
4	110	10120	46	69	92	116	138	184	1	00	000
	220	20240	92	138	185	231	276	369	2.0	3.2	4.0
3	110	12100	49	73	97	122	146	194	0	000	0000
	220	24200	97	146	195	244	291	390	2.0	3.2	4.0
2	110	14410	52	77	103	129	156	206	00	0000	250000
	220	28820	103	155	206	258	310	412	2.0	3.2	3.8
1	110	17160	55	82	109	137	164	218	000	250000	350000
	220	34320	109	164	219	273	328	437	2.0	3.0	4.1
0	110	20350	58	87	116	145	174	232	0000	350000	400000
	220	40700	116	174	232	290	348	464	2.0	3.3	3.8
00	110	24200	62	92	123	154	184	246	250000	400000	500000
	220	48400	123	185	246	308	369	492	1.9	3.0	3.7
000	110	28820	65	98	130	163	196	260	300000	500000	700000
	220	57640	130	196	261	326	392	521	1.7	3.0	4.1
0000	110	34320	71	106	142	177	212	284	400000	600000	800000
	220	68640	142	213	284	354	426	568	1.9	2.8	3.7
250000	110	38500	73	109	145	182	218	290	500000	750000	1000000
	220	77000	146	218	291	364	436	581	2.0	3.0	4.0
300000	110	44000	76	114	153	191	228	306	600000	900000	1200000
	220	88000	153	229	306	382	457	612	2.0	3.0	4.0
350000	110	49500	79	119	158	198	238	316	700000	1000000	1400000
	220	99000	158	238	317	396	476	635	2.0	3.0	4.0
400000	110	55000	81	122	163	204	244	326	800000	1200000	1600000
	220	110000	163	244	326	407	488	652	2.0	3.0	4.0
500000	110	64900	86	129	172	216	258	344	1000000	1500000	2000000
	220	129800	173	259	345	432	517	689	2.0	3.0	4.0

TABLE XIX

TABLE OF NATIONAL ELECTRICAL CODE CARRYING CAPACITIES

B. and S. or A. W. G.	Diameter of solid wire in inches	Area in circular mils.	Carrying capacity in amperes. Rubber covered wire	Carrying capacity in amperes. Other insulation	Feet per ohm resistance
18	0.0403	1624	3	5	150.4
16	0.05082	2583	6	8	239.2
14	0.06707	4107	12	16	380.3
12	0.08081	6530	17	23	604.6
10	0.1019	10380	24	32	961.1
8	0.1285	16510	33	46	1529
6	0.1620	26250	46	65	2431
5	0.1819	33100	54	77	3065
4	0.2043	41740	65	92	3864
3	0.2294	52630	76	110	4873
2	0.2576	66370	90	131	6145
1	0.2893	83690	107	156	7749
0	0.3249	105500	127	185	9769
00	0.3648	133100	150	220	12324
000	0.4096	167800	177	262	15537
0000	0.460	211600	210	312	19593
Circular Mils.		200000	200	300	18518
		300000	270	400	27778
		400000	330	500	37037
		500000	390	590	46296
		600000	450	680	55556
		700000	500	760	64815
		800000	550	840	74074
		900000	600	920	83333
		1000000	650	1000	92593
		1100000	690	1080	101852
		1200000	730	1150	111111
		1300000	770	1220	120370
		1400000	810	1290	129630
		1500000	850	1360	138889
		1600000	890	1430	148148
		1700000	930	1490	157407
		1800000	970	1550	166667
		1900000	1010	1610	175926
		2000000	1050	1670	185185

LIGHT EFFICIENCY TABLES

Table XX is prepared to facilitate the calculation of the most economical efficiency at which incandescent lamps may be used. The cost of incandescent lighting to the consumer may be taken as the sum of the cost of energy plus the cost of lamp renewals. The cost of energy in proportion to light obtained can be reduced by heating the filament to a greater

degree, but this shortens the life of lamp. For each cost of lamp and price of current there is, therefore, one certain efficiency at which lamps should be used to obtain light at the least cost. If the cost of energy is low, we can afford to waste electrical energy in order to lengthen life of lamp. If cost of energy is high, it will generally be found economical to sacrifice life of lamp in order to save energy.

The table gives the cost per 1,000 hours of lamp renewals at various prices per watt and various lengths of life of lamps. The table is based on watts because all incandescent lamps are now rated in watts. The performance of lamps, however, should be given in lumens and in the different tables pertaining to tungsten, tantalum, carbon and gem lamps the lumens per watt are given in connection with the life of lamps at that efficiency. It will be seen from the tables that invariably as the voltage on any lamp is reduced the life of lamp is lengthened and the quantity of light (which is expressed in lumens) reduced.

All incandescent lamps have now three voltages marked upon them, known respectively as "Top," "Middle" and "Bottom." In order to find which of these is the most economical we first note the number of lumens per watt and the corresponding length of life. Tracing down in Table XX under the proper length of life until we come to the horizontal line in which the cost of lamp per watt is found we note there the cost of lamp renewals for 1,000 hours. This, added to the cost of energy per K.W., gives us the total cost for the number of lumens corresponding to the length of life considered.

Dividing this cost by the number of lumens we obtain the cost per lumen. By comparing these costs per lumen at various voltages and lamps of different efficiency we can soon determine which is the more economical.

Example: Suppose we wish to find which is the most economical voltage at which a 150-watt tungsten lamp can be used, cost of lamp being 1 cent per watt and energy being charged for at the rate of 6 cents per K.W. The lumens per watt are given as follows: (See tables under "Incandescent Lamps," Chapter VII).

Top voltage. Lumens per watt, 8.30; life, 1,000 hours.
Middle voltage per watt, 7.97; life, 1,300 hours.
Bottom voltage per watt, 7.67; life, 1,700 hours.

Turning to Table XX we find cost of lamp renewals at 1 cent per watt and life of 1,000 hours to be 1 cent; at 1,300 hours, 0.77, and at 1,700 hours, 0.59 cent.

At the top voltage the total cost of light is 7 cents, which cost brings us 8.30 lumens or 1.0431 lumens for 1 cent.

At the middle voltage the total cost is 6.77 cents, which brings us 7.97 lumens, or 1.018 lumens for 1 cent.

At bottom voltage the total cost is 6.59 cents and here we obtain 7.67 lumens, or 1.016 lumens for 1 cent.

Taking the cost of energy at 1 cent per K.W. we have at top voltage 8.30 lumens for 2 cents or 4.15 lumens for 1 cent.

At middle voltage we have 7.97 lumens for 1.77 cents or 4.50 lumens for 1 cent.

At bottom voltage we have 7.67 lumens for 1.59 cent or 4.82 lumens for each cent.

The above calculations give only proportional values and such is all that is necessary to determine the best economy. If we wish to learn the total cost of light it is best to use the full wattage of the lamp and multiply cost given in Table XX by this and further multiply the wattage of lamp by price per K.W. and add the two the result will be the total cost of light for 1,000 hours for one lamp.

If the case is one of comparing free lamp renewals of carbon lamps for instance, with Mazda tungsten, or other lamps we take for the free lamps only the cost of electrical energy.

Turning to table of ratings of carbon filament lamps we find for instance that a 50-watt lamp at top voltage gives 3.49 lumens per watt. If the cost of electrical energy is 1 cent per K.W. we receive here 3.49 lumens for 1 cent as against 4.82 from tungsten lamps, showing that even at this low cost of current it is more economical to buy the latter than to accept the first free.

It is generally a difficult matter to make users of incandescent lamps understand the waste caused by the use of lamps of low efficiency. Thousands of lamps that give almost no light at all are in daily use simply because the light they give is sufficient to get along with and the owner deems it a waste to supply a new efficient lamp as long as the old one serves the purpose however poorly. As soon as the

TABLE XX

Table Showing Cost of Lamp Renewals Per Watt Per 1000 Hours.

LIFE OF LAMPS IN HOURS

Cost of Lamps in Cents Per Watt.	500	600	650	700	750	800	850	900	950	1000	1100	1200	1300	1400	1500	1600	1700	1800
.10	.200	.166	.154	.143	.133	.125	.118	.111	.105	.100	.091	.083	.077	.072	.067	.062	.059	.056
.20	.400	.333	.309	.286	.266	.250	.236	.222	.210	.200	.182	.166	.154	.144	.134	.124	.118	.112
.30	.600	.500	.462	.429	.400	.375	.354	.333	.315	.300	.273	.249	.231	.216	.201	.186	.177	.168
.40	.800	.667	.616	.572	.533	.500	.472	.444	.420	.400	.364	.333	.308	.288	.268	.248	.236	.224
.50	1.00	.833	.770	.715	.666	.625	.590	.555	.525	.500	.455	.415	.385	.360	.335	.310	.295	.280
.60	1.20	1.00	.924	.858	.800	.750	.708	.666	.630	.600	.546	.498	.462	.432	.402	.372	.354	.336
.70	1.40	1.17	1.08	1.00	.932	.875	.826	.777	.735	.700	.637	.581	.539	.504	.469	.434	.413	.392
.80	1.60	1.33	1.23	1.14	1.06	1.00	.944	.888	.840	.800	.728	.664	.616	.576	.536	.496	.472	.448
.90	1.80	1.50	1.38	1.28	1.20	1.12	1.06	1.00	.945	.900	.819	.747	.693	.648	.608	.558	.531	.504
1.00	2.00	1.66	1.54	1.43	1.33	1.25	1.18	1.11	1.05	1.00	.910	.833	.770	.720	.670	.620	.590	.560
1.10	2.20	1.83	1.69	1.57	1.46	1.38	1.30	1.22	1.15	1.10	1.01	.914	.847	.792	.737	.682	.649	.616
1.20	2.40	2.00	1.85	1.72	1.60	1.50	1.42	1.33	1.26	1.20	1.10	1.00	.924	.864	.804	.744	.708	.672
1.30	2.60	2.17	2.00	1.86	1.73	1.63	1.54	1.44	1.37	1.30	1.19	1.08	1.00	.936	.871	.806	.767	.728
1.40	2.80	2.33	2.16	2.00	1.86	1.75	1.66	1.55	1.47	1.40	1.28	1.16	1.08	1.00	.938	.868	.826	.784
1.50	3.00	2.50	2.31	2.15	2.00	1.88	1.78	1.66	1.57	1.50	1.37	1.24	1.16	1.07	1.00	.930	.885	.840
1.60	3.20	2.66	2.46	2.29	2.14	2.00	1.90	1.77	1.67	1.60	1.46	1.33	1.24	1.14	1.07	1.00	.944	.896
1.70	3.40	2.83	2.62	2.43	2.27	2.12	2.02	1.88	1.78	1.70	1.55	1.41	1.32	1.21	1.14	1.06	1.00	.952
1.80	3.60	3.00	2.77	2.57	2.40	2.25	2.14	2.00	1.89	1.80	1.64	1.50	1.40	1.28	1.21	1.12	1.06	1.00
2.00	4.00	3.33	3.08	2.85	2.67	2.50	2.38	2.22	2.10	2.00	1.82	1.67	1.56	1.42	1.35	1.24	1.18	1.12
2.20	4.40	3.66	3.39	3.14	2.94	2.75	2.62	2.44	2.31	2.20	2.00	1.84	1.70	1.56	1.49	1.36	1.30	1.23
2.40	4.80	4.00	3.70	3.43	3.21	3.00	2.85	2.66	2.52	2.40	2.18	2.00	1.85	1.70	1.63	1.48	1.42	1.35
2.60	5.20	4.33	4.01	3.72	3.48	3.25	3.09	2.88	2.73	2.60	2.36	2.17	2.00	1.84	1.76	1.60	1.54	1.47
2.80	5.60	4.66	4.32	4.00	3.75	3.50	3.32	3.10	2.94	2.80	2.54	2.33	2.16	1.98	1.90	1.72	1.66	1.59
3.00	6.00	5.00	4.63	4.29	4.02	3.75	3.56	3.32	3.15	3.00	2.72	2.50	2.31	2.12	2.04	1.84	1.77	1.70

TABLE XXI

TABLE SHOWING CHANGE IN CANDLE POWER OF INCANDESCENT LAMPS WITH CHANGES IN VOLTAGE.

PER CENT CHANGE IN VOLTAGE		PER CENT CHANGE IN CANDLE POWER			
		Carbon	Gem	Tantalum	Tungsten
INCREASE ABOVE NORMAL	10	69.8	58.0	51.4	42.1
	9	61.4	51.3	45.5	37.4
	8	53.4	44.7	39.8	32.8
	7	45.6	38.4	34.2	28.3
	6	38.2	32.3	28.9	23.9
	5	31.1	26.4	23.6	19.7
	4	24.3	20.7	18.6	15.5
	3	17.9	15.2	13.7	11.5
	2	11.6	10.0	9.0	7.6
	1	5.7	4.9	4.0	3.7
NORMAL		0	0	0	0
DECREASE BELOW NORMAL	1	5.4	4.7	4.3	3.7
	2	10.6	9.3	8.4	7.2
	3	15.5	13.6	12.4	10.6
	4	20.3	17.8	16.2	13.9
	5	24.8	21.8	20.0	17.2
	6	29.0	25.7	23.6	20.4
	7	33.2	29.4	27.1	23.4
	8	37.1	33.0	30.5	26.4
	9	40.7	36.4	33.6	29.3
	10	44.3	39.7	36.8	32.2

G. S. Merrill.—Proceedings American Institute of Electrical Engineers, September, 1910.

candle power of a lamp drops off noticeably it should be replaced by a new one. If the light which it is giving is still sufficient it should be replaced by a lower candle power lamp. The saving of energy will be much greater than the additional cost of lamp. Consider the following example: A 50-watt carbon lamp burning 1,000 hours at 6 cents per K.W. will consume $3.00 worth of energy. If allowed to burn another 1,000 hours its candle power will drop off about one-half while the current consumption will

remain about the same. If only 8 candle power are wanted it could be thrown away and replaced with an 8 candle power lamp which would cost about 20 cents and save half or $1.50 in current.

It is generally considered good policy to smash incandescent lamps when their candle power has been reduced to about 80 per cent of its initial value. And it is far better and more economical to use lamps of the lowest candle power needed and renew them frequently than to let a larger candle power lamp burn at low efficiency.

CHAPTER XIX

GLOSSARY OF TERMS AND PHRASES

Actinic Rays.—These are the rays of light that cause chemical changes. A light producing strong chemical action or one which strongly affects photographic plates is said to be highly actinic.

Albedo.—The term albedo refers to the reflecting power of substances. Thus, a body reflecting only one-half of the light received, is said to have an albedo of 0.50.

Alternating Current.—Alternating currents of electricity differ from direct currents in a way that seriously affects many of the illuminants. Before deciding upon the installation of a system of illumination it is always necessary to consider whether the current supply will be direct or alternating. If alternating the frequency must also be taken into consideration.

Ampere.—The ampere is the unit of current strength. It measures the rate of flow. If the voltage and other conditions of the circuit remain unchanged it may also be taken as a comparative measure of the energy being consumed. Thus, if two devices be connected in the same circuit a comparison

of the amperage will also be a comparison of the power consumed by the two devices.

Candle Power.—This term as commonly used denotes the light giving power of a lamp. Unless qualified by one of the following terms such as, hemispherical, apparent, etc., its meaning is very loose as the candle power of most lamps varies greatly at different angles.

Apparent Candle Power.—This term is generally applied only to lamps equipped with special concentrating reflectors which liimt the light to a small area. This rating is usually given for a specified distance in feet. The value of the apparent candle power depends more upon the reflector than upon the lamp.

Equivalent Candle Power.—This term is used in referring to lights such as the Moore tube or the mercury vapor lamp the light of which is emitted from a large area rather than from a point. It means that the total light emitted from such a source is equivalent to a point source of the stated mean spherical candle power.

Mean Horizontal Candle Power.—This expresses the average candle power given out in the horizontal plane.

Mean Lower Hemispherical Candle Power.—The average candle power in the lower hemisphere.

Mean Spherical Candle Power.—This denotes the average intensity of the lamp. It is the only term of general value. By multiplying the mean spherical intensity by 12.56 we obtain the total number of lumens emitted.

Maximum Candle Power.—This denotes the maximum intensity of illumination obtained in any direction from any lamp.

Mean Zonular Candle Power.—This refers to the mean intensity given out in any zone considered.

Chiaroscuro.—The particular distribution of the lights and shades of a piece with respect to the whole piece and the ease of the eye.

Coefficient of Reflection.—This term denotes the percentage of light received that will be reflected by a body. The higher the coefficient of reflection the greater the reflecting power.

Cosine Law of Illumination.—The intensity of illumination of a surface receiving light from a point source varies as the cosine of the angle of incidence of the rays of light upon the surface illuminated.

Diffusion.—Diffuse reflection occurs when rays of light are reflected from irregular surfaces. The ordinary diffusion of light in transmission is brought about by irregular transmitting surfaces such as ground glass. The light source is apparently much weakened by diffusion, but this is due to the fact that the light is given off from a larger surface. Diffusing globes are used for the purpose of reducing the intrinsic brilliancy and the larger the globe the greater the reduction

Efficiency of Electric Lamps.—The term efficiency is here used in a manner differing from the ordinary use of the word. Ordinarily efficiency is expressed in percentage of 1.00 and the nearer 1.00 the efficiency the more satisfactory is the statement.

In illumination the term denotes the number of

watts per candle power. Thus, a nominal 16 c.p. lamp requiring 55 watts would be considered as having an efficiency of about 3.5 watts per candle power. Used in this way the term is as loose as is the use of the word candle power without qualification.

The efficiency of electric lamps may be properly stated either in lumens per watt at terminals of lamp or in watts per mean spherical candle power.

Fluorescence.—This is a characteristic possessed by some bodies which enables them to become luminous when under the influence of radiant energy.

Fluorescent Screen.—A screen having fluorescent material on its surface.

Foot Candle.—The foot candle is the common unit of illumination. It is the intensity of illumination produced by a source of light of 1 candle power at a distance of one foot from that source, the light falling perpendicularly. In place of foot candle the phrase, lumens per square foot, is also used. The number of lumens per square foot and the number of foot candles will always be the same.

Frequency.—This term applies only to alternating currents. Frequencies of 60 and 25 cycles are common. When buying or ordering for alternating current circuits it is essential to take into consideration the frequency.

Geissler Tube.—A sealed glass tube containing highly rarefied gases, either with or without fluorescent material. Luminous effects are produced by an electric discharge through tube.

Hefner.—The German unit of candle power equal to 0.9 international candle.

Horse Power.—An electrical horse power is equal to 746 watts or 0.75 K.W. The horse power expresses the rate of doing work and is found by multiplying the amperes and volts together and dividing by 746. In alternating current circuits the above must be multiplied by power factor.

Illuminometer.—An instrument used to compare or measure intensity of illumination by the user's ability to distinguish letters or other objects.

Illuminometry. See photometry.

Infra Red Rays.—The invisible rays in the spectrum of a source of light that are longer than the red rays.

Intrinsic Brilliancy.—This is the candle power per unit area of a source of light. It is usually expressed in candle power per square inch.

Kilowatt.—1,000 watts.

Kilowatt Hour.—This is the common unit upon which meter charges are computed. Commonly the statement that one kilowatt or K.W. has been used means that energy at the rate of 1,000 watts has been used for one hour or 250 watts for 4 hours or at any rate so that the product of the rate of consumption multiplied by the time in hours amounts to 1,000.

Lumen.—This is the unit of flux or quantity of light. It is equal to 1/12.56 of the total flux of light emitted by a source of light having an intensity of one mean spherical candle power.

A source of light equal to one mean spherical candle power will give out 12.56 lumens.

Lumens Per Square Foot.—This expresses the flux of light falling upon a surface. See foot candles.

Lumens Per Watt.—This term expresses the real

efficiency of electric lamps. It tells how much light is obtainable per unit of energy expended. It is found by dividing the total lumens given out by any lamp by the wattage of the lamp.

Lumens Effective.—This term is used to denote the number of lumens of a given unit that are available on the working plane.

Luminous Flux.—This is the total flux of light in any direction.

Luminescence.—A limited power of emitting light possessed by certain bodies after having acquired potential energy by exposure to light or radiant energy.

Luminosity.—The quality of being luminous. Luminosity is equal to illumination multiplied by the coefficient of reflection or transmission as the case may be.

Luminous Efficiency.—This is the ratio of the luminous radiation, to the entire radiant energy given out by a source of light. It is found by dividing the luminous energy by the total radiant energy.

Lux.—The lux is sometimes used as the unit of flux of light. A surface of one square meter when at a distance of one meter from a source of light of one candle power will be illuminated to the intensity of one lux provided the light falls upon it perpendicularly.

Meter Candle.—This is the amount of light given by a source of one candle power at a distance of one meter from the source provided the rays strike the surface squarely. 10.76 meter candles equal one foot candle.

Phosphorescence.—The capacity to give out a faint light without sensible heat.

Photometer—This is an instrument used to measure or compare intensities of light.

Photometry.—Referring to the art of measuring intensity of light.

Power Factor.—This term is used only in connection with alternating currents. It expresses the fact that in alternating current work the power is not always proportional to the product of the volts and amperes but generally less. The power factor is always less than unity and the product of the volts and amperes must be multiplied by it to obtain the real power consumption in the circuit.

Arc lamps and other devices containing electro magnets always produce unsatisfactory power factor conditions.

Purkinje Effect.—The variation in visual acuity with lights of different colors. If, for instance, red and blue objects be compared in a gradually diminishing illumination, the blue will become comparatively more conspicuous and the red more obliterated. For this reason colors should always be compared in good light.

Refraction of Light.—This refers to the change in the direction of rays of light which takes place when they pass from air into glass or water; or from glass or water into air or from any medium into another of different density.

Specific Brightness.—See intrinsic brilliancy.

Spectra.—Plural of spectrum.

Spectroscope.—This is an optical instrument used

for examining the spectra. By its use it is possible to determine by means of the spectral lines the composition of the substance which is at the basis of the light giving rays passing into the spectroscope.

Spectrum.—The several colored and other rays of which light is composed separated by the refraction of a prism or other means and shown as spread on a screen or by direct vision.

Spherical Reduction Factor.—This is a constant, varying with different lamps, which, when multiplied by the mean horizontal candle power of an incandescent lamp will give the mean spherical candle power.

Temperature Coefficient of Resistance.—When the heating increases the electrical resistance of a conductor it is said to have a positive temperature coefficient of resistance and negative when the heating decreases the resistance.

Ultra Violet Rays.—The invisible rays of a source of light that are shorter than the violet rays.

Visual Acuity.—The ability to perceive detail. This varies with lights of different color, also with the intensity of illumination and arrangement of lights.

Volt.—The electrical unit of pressure. In direct current circuits the product of volts and amperes equals watts. In alternating (A.C.) circuits the above must be multiplied by power factor.

Watt.—The electrical unit of power, equal to product of volts and amperes in direct current circuits.

CHAPTER XX.

TABLES OF SQUARE ROOTS AND STANDARD SYMBOLS.

The tables of square roots given in this chapter will greatly facilitate calculations involving the squaring of numbers or the extraction of square roots. This becomes frequently necessary in armature and magnet calculations.

There are two tables, each covering two pages. One of these tables is to be used for numbers from .1 to 99.9, inclusive, and the other for numbers from 1 to 999.

The first one or two figures of every number between these limits is given in the first left-hand column. If there are three figures in the number the third one will be found at the head of one of the columns to the right. For instance, if the number of which we desire to find the square root is 233, we find 23 in the first column at the left and the remaining 3 in the column at the right headed "3." If the number of which we wish to find the square root consists of only two numbers, we find the first number in the column at the left and the remaining number in one of the columns at the right. For instance, if we

have the number 36, we go down the first column to figure 3 and in line with this figure and under the column headed "6" we will find the square root.

The root of a whole number consists of a whole number and a decimal. The whole number is found under the column headed "0" and the decimal under one of the columns at the right. For instance, the square root of 233 is 15.26, the whole number (15) being found under the column headed "0" and the decimal (.26) under the column headed "3." The whole numbers in the column headed "0" hold for all the numbers following until a larger whole number is given. Wherever in any line the numbers are underlined these numbers belong to the next higher whole number. For instance, the square root of 259 is 16.09, the whole number (16) being found ahead of this number instead of the number following it.

Whenever the root of a number carried to more decimal points, or smaller than any number given in the table, is wanted, we may multiply this number by 100, find the root of this product and divide it by 10; the result will be the square root desired. Example: Find the square root of .475. Moving the decimal point two figures to the right, which effects the multiplication, we have 47.5. The square root of this is 6.89. Moving the decimal point one figure to the left, we have .689, which is the square root of .475.

In case multiplication by 100 does not bring the number within range of the tables, multiplication by any other number will do as well, provided that the subsequent division is made by the square root of the multiplier.

If the number is larger than any given in the table we reverse the process and divide by some convenient number and multiply by the root of that number.

SQUARE ROOTS 1. TO 999.

	0	1	2	3	4	5	6	7	8	9
0	0.00	1.00	1.41	1.73	2.00	2.24	2.45	2.65	2.83	3.00
1	3.16	32	46	61	74	87	00	12	24	36
2	4.47	58	69	80	90	00	10	20	29	39
3	5.48	57	66	74	83	92	00	08	16	25
4	6.32	40	48	56	63	71	78	86	93	00
5	7.07	14	21	28	35	42	48	55	62	68
6	75	81	87	94	00	06	12	19	25	31
7	8.37	43	49	54	60	66	72	78	83	89
8	94	00	06	11	16	22	27	33	38	43
9	9.49	54	59	64	70	75	80	85	90	95
10	10.00	05	10	15	20	25	30	34	39	44
11	48	54	58	63	67	72	77	82	86	91
12	95	00	05	09	14	18	23	27	31	36
13	11.40	45	49	53	58	62	66	70	75	79
14	83	87	92	96	00	04	08	12	17	21
15	12.25	29	33	37	41	45	49	53	57	61
16	65	69	73	77	81	85	88	92	96	00
17	13.04	08	11	15	19	23	27	30	34	38
18	42	45	49	53	56	60	64	67	71	75
19	78	82	86	89	93	96	00	04	07	11
20	14.14	18	21	25	28	32	35	39	42	46
21	49	53	56	59	63	66	70	73	76	80
22	83	87	90	93	97	00	03	07	10	13
23	15.16	20	23	26	29	33	36	39	43	46
24	49	52	56	59	62	65	68	72	75	78
25	81	84	87	91	94	97	00	03	06	09
26	16.12	16	18	22	25	28	31	34	37	40
27	43	46	49	52	55	58	61	64	67	70
28	73	76	79	82	85	88	91	94	97	00
29	17.08	06	09	12	15	18	20	23	26	29
30	32	35	38	41	44	46	49	52	55	58
31	61	64	66	69	72	75	78	80	83	86
32	89	92	94	97	00	03	06	08	11	14
33	18.16	19	22	25	28	30	33	36	38	41
34	44	47	49	52	55	57	60	63	65	68
35	71	74	76	79	81	84	87	89	92	95
36	97	00	03	05	08	11	13	16	18	21
37	19.24	26	29	31	34	36	39	42	44	47
38	49	52	54	57	60	62	65	67	70	72
39	75	77	80	82	85	87	90	92	95	98
40	20.00	03	05	07	10	12	15	17	20	22
41	25	27	30	32	35	37	40	42	45	47
42	49	52	54	57	59	62	64	66	69	71
43	74	76	78	81	83	86	88	90	93	95
44	98	00	02	05	07	09	12	14	17	19
45	21.21	24	26	28	31	33	35	38	40	42
46	45	47	49	52	54	56	59	61	63	66
47	68	70	73	75	77	79	82	84	86	89
48	91	93	95	98	00	02	05	07	10	11
49	22.14	16	18	20	23	25	27	29	32	34

Square Roots 1. to 999.

	0	1	2	3	4	5	6	7	8	9
50	22.36	38	40	43	45	47	50	52	54	56
51	58	61	63	65	67	69	72	74	76	78
52	80	83	85	87	89	91	93	96	98	00
53	23.02	04	07	09	11	13	15	17	19	22
54	24	26	28	30	32	35	37	39	41	43
55	45	47	49	52	54	56	58	60	62	64
56	66	69	71	73	75	77	79	81	83	85
57	87	90	92	94	96	98	00	02	04	06
58	24.08	10	12	15	17	19	21	23	25	27
59	29	31	33	35	37	39	41	43	45	47
60	50	51	54	56	58	60	62	64	66	68
61	70	72	74	76	78	80	82	84	86	88
62	90	92	94	96	98	00	02	04	06	08
63	25.10	12	14	16	18	20	22	24	26	28
64	30	32	34	36	38	40	42	44	46	48
65	50	51	53	55	57	59	61	63	65	67
66	69	71	73	75	77	79	81	83	85	87
67	89	90	92	94	96	98	00	02	04	06
68	26.08	10	12	13	15	17	19	21	23	25
69	27	29	31	32	34	36	38	40	42	44
70	46	48	50	51	53	55	57	59	61	63
71	65	66	68	70	72	74	76	78	80	81
72	83	85	87	89	91	93	94	96	98	00
73	27.02	04	06	07	09	11	13	15	17	18
74	20	22	24	26	28	29	31	33	35	37
75	39	40	42	44	46	48	50	51	53	55
76	57	59	60	62	64	66	68	69	71	73
77	75	77	78	80	82	84	86	87	89	91
78	93	95	96	98	00	02	04	05	07	09
79	28.10	13	14	16	18	20	21	23	25	27
80	28	30	32	34	35	37	39	41	43	44
81	46	48	50	51	53	55	57	58	60	62
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85	29.15	17	19	21	22	24	26	27	29	31
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88	66	68	70	72	73	75	77	78	80	82
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SQUARE ROOTS .1 to 99.9

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Square Roots .1 to 99.9

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98	90	90	91	91	92	92	93	93	94	94
99	95	95	96	96	97	98	98	99	99	99

STANDARD SYMBOLS FOR WIRING PLANS

As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.

Ceiling Outlet; electric only. Numeral in center indicates number of standard 16 c. p. incandescent lamps.

Ceiling Outlet; combination. 4-2 indicates 4-16 c. p. standard incandescent lamps and 2 gas burners.

Bracket Outlet; electric only. Numeral in center indicates number of standard 16 c. p. incandescent lamps.

Bracket Outlet; combination. 4-2 indicates 4-16 c. p. standard incandescent lamps and 2 gas burners.

Wall or Baseboard Receptacle Outlet. Numeral in center indicates number of standard 16 c. p. incandescent lamps.

Floor Outlet. Numeral in center indicates number of standard 16 c. p. incandescent lamps.

Outlet for Outdoor Standard or Pedestal; electric only. Numeral indicates number of stand. 16 c. p. incan. lamps.

Outlet for Outdoor Standard or Pedestal; combination. 6-6 indicates 6-16 c. p. stand. incan. lamps; 6 gas burners.

Drop Cord Outlet.

One Light Outlet, for lamp receptacle.

Arc Lamp Outlet.

Special Outlet, for lighting heating and power current, as described in specifications.

Ceiling Fan Outlet.

S. P. Switch Outlet.

D. P. Switch Outlet.

3-Way Switch Outlet.

4-Way Switch Outlet.

Show as many symbols as there are switches. Or in case of a very large group of switches, indicate number of switches by a Roman numeral, thus: S XII; meaning 12 single pole switches.

Describe type of switch in specifications, that is,

Flush or surface push button or snap.

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STANDARD SYMBOLS FOR WIRING PLANS

As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.

Automatic Door Switch Outlet.

Electrolier Switch Outlet.

Meter Outlet.

Distribution Panel.

Junction or Pull Box.

Motor Outlet; numeral in center indicates horse power.

Motor Control Outlet.

Transformer.

Main or feeder run concealed under floor.

Main or feeder run concealed under floor above.

Main or feeder run exposed.

Branch circuit run concealed under floor.

Branch circuit run concealed under floor above.

Branch circuit run exposed.

Pole line.

● Riser.

SUGGESTIONS IN CONNECTION WITH STANDARD SYMBOLS FOR WIRING PLANS.

Indicate on plan, or describe in specifications, the height of all outlets located on side walls.

It is important that ample space be allowed for the installation of mains, feeders, branches and distribution panels.

It is desirable that a key to the symbols used accompany all plans.

If mains, feeders, branches and distribution panels are shown on the plans, it is desirable that they be designated by letters or numbers.

STANDARD SYMBOLS FOR WIRING PLANS

As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.

Telephone Outlet; private service.

Telephone Outlet; public service.

Bell Outlet

Buzzer Outlet.

Push Button Outlet; numeral indicates number of pushes.

Annunciator; numeral indicates number of points.

Speaking Tube.

Watchman Clock Outlet.

Watchman Station Outlet.

Master Time Clock Outlet.

Secondary Time Clock Outlet

Door Opener.

Special Outlet; for signal systems, as described in specifications

Battery Outlet.

Circuit for clock, telephone, bell or other service run under floor, concealed.
Kind of service wanted ascertained by symbol to which line connects.

Circuit for clock, telephone, bell or other service run under floor above concealed.
Kind of service wanted ascertained by symbol to which line connects.

NOTE—If other than standard 16 c. p. incandescent lamps are desired, specifications should describe capacity of lamp to be used.

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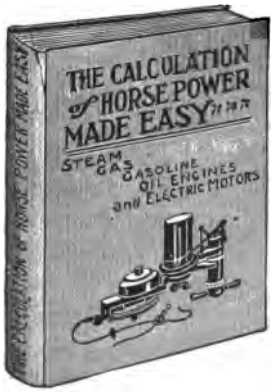

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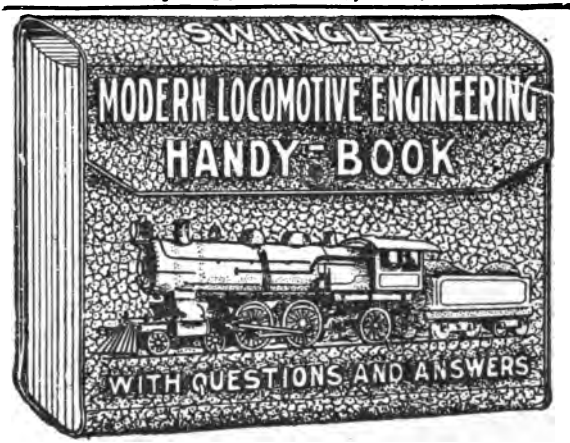

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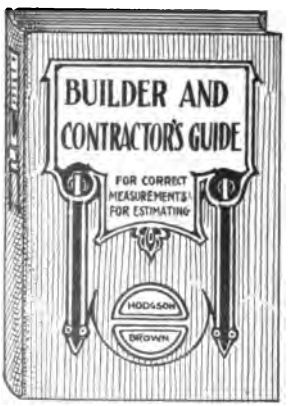

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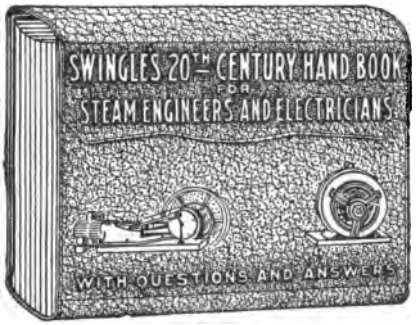

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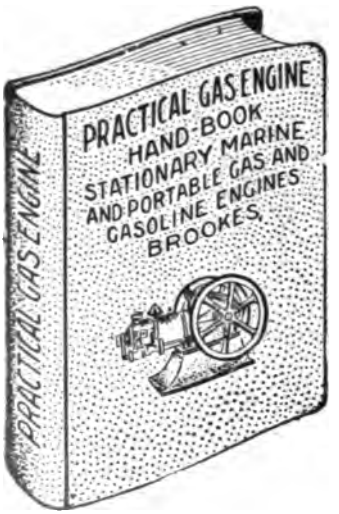

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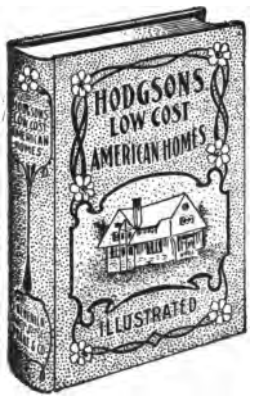

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